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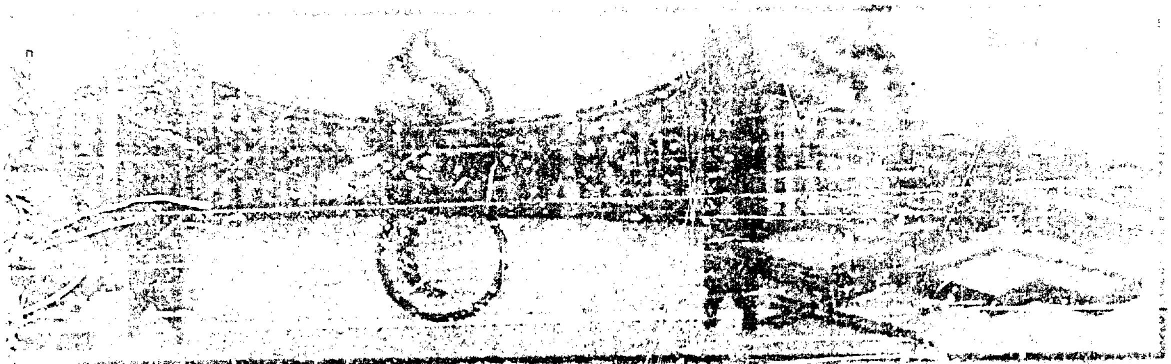

TECHNICAL REPORT

DB-TR: 6-59

...ISHMENT OF SAFETY DESIGN CRITERIA FOR USE IN ENGINEERING OF EXPLOSIVE FACILITIES AND OPERATIONS

REPORT NO. 2

DETONATION BY FRAGMENT IMPACT

BY

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... TO ... MAY 1959

INDUSTRIAL ENGINEERING DIVISION

PICATINNY ARSENAL — DOVER, NEW JERSEY

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ESTABLISHMENT OF SAFETY DESIGN CRITERIA FOR USE IN ENGINEERING OF EXPLOSIVE FACILITIES AND OPERATIONS

Report No. 2

DETONATION BY FRAGMENT IMPACT

BY

RICHARD M. RINDNER

PROJECT NO.:

REPORT NO.: DB-TR: 6-59

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SECTION I

INTRODUCTION

The first part of this project (Ref. 1.) dealt primarily with propagation of detonation due to blast effects and with minimum safe distances necessary for the separation of two or more explosive systems. This work also indicated that fragments resulting from detonation of the donor explosive have a much greater effect in causing detonation in the acceptor explosive than pure blast.

It is the intent of this second report, as part of the overall project dealing with the establishment of more realistic safety design criteria for explosives storage and manufacture, to deal with the effects of fragment impact in causing a high-order detonation in the acceptor charge.

Several theoretical studies, supported by actual experience and planned experiments, were conducted in Great Britian during, and immediately after World War II. Investigated were such factors as fragment velocity, casing thickness, explosive sensitivity, energy required for penetration, and residual velocities after penetration of various shells and bombs (Ref. 2, 3, 4, 5). The study covered by this report is based primarily on the work cited, and attempts to interrelate these parameters in order to predict the possibility of high-order mass detonation occurrence if a single unit should detonate high-order. It is believed that this study will be useful in establishing a basis for the design of explosive manufacturing and storage facilities.

SECTION II

SUMMARY

A method has been established for predicting the vulnerability to high-order detonation of an explosive system (or vulnerability to mass detonation of adjacent explosive systems) in terms of geometry of the system (e.g. casing-explosive weight ratio, casing thickness) and explosive properties. The empirical relationships used to calculate fragment velocities and fragment size distributions had been previously developed by other investigations on the basis of controlled tests in which single regular fragments were fired against various explosives having different degrees of shielding, as well as controlled tests in which a variety of shells and bombs of different sizes with different explosive fillers were detonated.

Comparison of actual data (both British and Picatinny Arsenal reports) on fragment size distribution for items of various sizes with corresponding distributions calculated by the relationship incorporated in the above-mentioned prediction method, show reasonably close agreement. Moreover, application of the method to various shell and rocket heads to determine whether or not each of these items is potentially mass-detonating, yields results which are generally consistent with present regulations given in the Ordnance Safety Manual, ORDM7-224.

It is emphasized that although the procedure detailed in this report was developed on the basis of tests conducted with so-called conventional ammunition items containing standard explosive fillers, its real significance in a

much broader sense is that it is potentially applicable to any explosive system or systems (e.g. the newer high-energy propellant systems, reaction or mixing vessels in propellants and explosive manufacture) for prediction of sensitivity and/or mass-detonability.

SECTION III

CONCLUSIONS

1. A procedure has been developed whereby, knowing the overall geometry and dimensions of an explosive system, as well as certain explosive and confinement characteristics (which, if not already available, can be determined by small scale tests), the sensitivity of the system can be determined and a reasonably reliable prediction made as to its vulnerability to high order detonation by fragment impact (or its potential ability to contribute to propagation of an explosion, when considered in relation to any specific environment of adjacent explosive systems) by a straightforward series of calculations.

2. Application of the proposed procedure or portions thereof to various shell and rocket heads yields results which are generally in agreement with the Ordnance Safety Manual (with a few exceptions) as to the ability of these items to mass-detonate, as well as with actual data on fragment size distributions. This agreement supports the reliability of applying the proposed procedure to predict potential behavior in such highly important cases as those involving the newer high-energy propulsion systems, and in-process situations (e.g. nitration reactions, propellant mixing operations).

SECTION IV

RECOMMENDATION

It is recommended that the methods outlined in this report be adopted for the calculation of output and sensitivity factors for explosive materials (particularly the newer high-energy propellant formulations), and for prediction of the gross mass-detonability characteristics of systems in which these materials are present. The latter application represents an initial screening which permits placement of an explosive system into either one of two categories, namely, (1) non-mass detonable (no distinction being made as to degree of probability) and (2) mass-detonable by fragment impact.

SECTION V

STUDY

Theoretical Background

A fragment resulting from the detonation of a cased explosive possesses a certain initial velocity depending on the explosive to casing weight ratio and the explosive output. If the fragment strikes an acceptor explosive with sufficient kinetic energy, it penetrates the shell and may cause detonation in the acceptor. The order of detonation (whether it be high order, low order deflagration or burning) depends on the kinetic energy of the fragment, material and thickness of casing, and sensitivity of the acceptor explosive. This can be represented in the following manner.

	Critical striking velocity	Boundary striking velocity
No action	Low order detonation Deflagration Burning	High order detonation

Striking Velocity

As indicated above, the critical velocity (V_c) represents that value below which a fragment of mass (m) will cause no action in an explosive of sensitivity (K) when surrounded by a casing of thickness (t).

Similarly the boundary velocity (V_s) is that value below which high order detonation will not occur. It is noted that the area between the critical velocity and boundary velocity is the area where occurrence of low order detonation, deflagration or burning is expected. It is the primary concern of this report

to establish means for predicting those cases in which high order detonation propagates from one explosive system to the next due to fragment impact. Therefore, boundary velocity is the only basis of interest and is used throughout this report. It will be shown by the equations presented below that one can predict the detonation susceptibility of any cased charge to high order detonation due to fragment impact, if the geometry and explosive characteristics of the system or systems under consideration are known. These equations may also be used to calculate explosive output and sensitivity factors, once the necessary fragment velocities and distributions have been measured.

One equation which deals with fragment initial velocity (Ref. 2.) is:

$$V_o = \left[\frac{E}{C} \times kf\right]^{1/2} \quad (1)$$

Where $\frac{E}{C}$ = explosive to casing wt. ratio (in lbs.)

k = constant designating explosive output

f = factor depending on $\frac{E}{C}$ ratio (Appendix A)

Another relationship worked out by Dr. Gurney of the Naval Ordnance Laboratory (Ref. 6.) and found to give results slightly higher than, but generally in good agreement with the above relationship, is

$$V_o = \sqrt{2E'} \left[\frac{E/C}{1 + E/2C}\right]^{1/2} \quad (2)$$

Where $\sqrt{2E'}$ is Gurney energy constant similar in function to (k) above, and $\left[\frac{E}{C}\right]$ is the explosive to casing wt. ratio.

The fragmentation pattern and the weight of the largest fragment

resulting from the high order detonation of any explosive system were calculated according to relationships developed on the basis of theoretical considerations and confirmed with a large number of tests (Ref. 2).

The number of fragments obtained from high order detonation of a shell is given as:

$$\ln N_{(x)} = \ln (C'M_A) - \frac{M}{M_A} \quad (3)$$

when $N_{(x)}$ = no. of fragments larger than (m), C' and M_A are fragment distribution constant and fragment distribution parameter respectively, and $M = m^{1/2}$ (square root of mass in ounces).

The fragment distribution parameter is defined by the equation

$$M_A = Bt_{av}^{5/6} \; d_i^{1/3} \left[1 + \frac{t_{av}}{d_i} \right] \quad (3a)$$

where

t_{av} = average thickness of the casing section being considered (inches)

d_i = average inside diameter of the casing (inches)

B = constant depending upon the explosive and casing material

The fragment distribution constant is defined by the equation

$$C' = \frac{C}{2M_A^3} \quad (3b)$$

where C = total weight of metal casing

The largest fragment produced in an explosion can be found by setting

$\ln N_{(x)} = 0$ in equation (3)

Thus $M = M_A \ln (C' M_A)$ (4)

In establishing the criteria for mass detonation of cased explosives the

donor fragments are assumed to have rectangular shape and be made of mild steel. The velocities on striking the acceptor are considered to be the same as the initial velocities of the fragments because of the assumed close proximity of the acceptor. A detonation is considered possible when the initial velocity of the fragment is equal to or greater than the minimum velocity which is necessary to penetrate the casing and still have sufficient kinetic energy to cause high order detonation of the explosive. This latter value is defined as the boundary velocity (V_s), and can be calculated, according to Reference 3, from the following equation:

$$V_s^2 = \frac{Ke^{(5.37\, t/m^{1/3})}}{m^{2/3}\,(1 + 3.3\, t/m^{1/3})} \qquad (5)$$

where K = explosive sensitivity constant, (derived experimentally)

t = thickness of the casing (inches)

m = mass of the fragment (oz.)

In order to allow for the most stringent conditions, the casing thickness (t) of the acceptor is taken as the thinnest portion of the casing and (m) is taken as the mass of the largest fragment produced by the donor shell (or that portion of the donor shell under consideration). In every case, therefore, the calculated values were for the largest fragment penetrating the thinnest casing (i. e. the severest possible case).

By combining the above relationships in the proper manner and applying them to any given situation it becomes possible to predict what the mass detonation characteristics are for any set of donor-acceptor conditions. It also becomes possible to determine what types of shielding or distance

separation are necessary to eliminate the hazard of mass detonation or propagation of detonation in any donor-acceptor situation. However, this latter aspect will be covered in a subsequent report.

RESULTS:

By means of equation (5) a series of graphs (Appendix D, Figures 1 through 6) were prepared, one for each of the more common explosives for which sensitivity data are available. These graphs show boundary velocity (V_B) as a function of fragment size (m) for constant values of casing thickness. The values of (K) used for each explosive were those given in reference 3 and are listed in Table 1. (Appendix B)

In order to predict the mass detonation characteristics of various shells and rocket heads, the fragmentation patterns were calculated from equations (3a) and (3b) and the size of the largest fragment was determined by setting equation (3) equal to zero and solving for (M)($M=m^{1/2}$). The initial fragment velocity of the donor was calculated using equation (1) and the velocity of the largest fragment produced by the donor which could detonate the acceptor high order (boundary velocity), was determined by reference to the graphs in figures 1 to 6. If the initial velocity of the donor fragments was found to be greater than the boundary velocity for the acceptor, then the item under consideration was considered mass-detonable. The results for a number of standard items loaded with TNT and Composition B are given in Table 2. In making these calculations the donor shells were considered in sections. Fragment initial velocity, fragment size, and boundary velocity were cal-

culated individually for each section.

Consideration of the donor shell in sections was necessary, since the equations used are based on the assumption of cylindrical cased charges (i.e. constant cross-sectional area) and uniform casing thickness; therefore, each item was divided into base, middle, and nose sections in such a way that equivalent cylinders could be constructed having average wall thickness, average charge diameter, and the same casing to charge weight ratio as the original section. (Only cylindrical portions in contact with the explosive were considered). For each section the fragment of largest mass and its corresponding initial velocity were calculated. The boundary velocity for each of these fragments was then determined assuming impact at the thinnest portion of the acceptor charge casing. Where the acceptor was shown to be mass-detonable, the size of the smallest fragment which could cause detonation, and the total number of fragments capable of causing detonation were calculated. The smallest fragment was found by setting (V_s) in equation (5) equal to (V_0) obtained from equation (1) and solving for (m). The number of fragments was determined by substituting this value of (m) in equation (3). The value of (m) can also be found from graphs 1 - 6 using (V_0) for (V_s). Table 3 gives a summary of all the items for which calculations were made and the comparison with present safety manual classification.

Table 4 shows a comparison of fragmentation patterns obtained in actual tests with those calculated from equation (3).

Appendix C gives a sample calculation in detail for a 90MM shell filled with TNT, and with composition B (Drawing No. 75-18-42).

DISCUSSION OF RESULTS:

In the derivation of boundary velocity, certain assumptions were made which are as follows:

(1) The fragment must penetrate the casing to cause high order detonation. (i. e. for any given fragment mass to cause detonation of a particular explosive, the same minimum kinetic energy must be available to the explosive after penetration losses which vary with casing thickness).

(2) The fragment striking the casing of the acceptor has the shape of a rectangular prism.

(3) The fragment strikes the casing of the acceptor normal to its surface.

(4) The fragment and the casing are of mild steel.

The assumption of rectangular shaped fragments and the normal angle of the fragment attack were made because these represent conditions under which boundary velocities would be minimized, thereby tending toward conservative predictions concerning vulnerability to mass detonation. The comparison of the results of actual tests agree well with the results predicted from these tests. From the results presented it can be seen that the sensitivity of the explosive in the acceptor is a major factor in classifying the mass detonation characteristics of an explosive system.

The fragmentation patterns. as obtained from the above formulas, were compared with the experimental results obtained at this Arsenal. The agreement is reasonably close for all rounds compared (81MM, 90MM and 155MM shells). Another comparison was made with the experimental results from Reference 7 and the calculated boundary velocity for 1/4 oz fragments striking 60/40 RDX/TNT explosive contained in 0.08 inch thick casing. The calculated value for boundary velocity using equation (5) is the same as the experimental value obtained in Reference 7. It is worth mentioning that the data in Reference 7 are completely independent of the data which formed the basis for this report.

A comparison of the calculated results for various types of ammunition with the Ordnance Safety Manual (Ref. 8) concerning mass detonability (Table 4) indicated good agreement with the following exceptions:

a. 90MM and 105MM shell filled with Composition B and 240MM shell filled with TNT, where the calculated values indicate a possibility of mass detonation occurrence while the Safety Manual excludes them from class 10 explosives.

b. 81MM M56 mortar shell filled with TNT where the calculated values indicate that mass detonation will not occur while the Safety Manual includes this item in the class 10 category.

FUTURE PLANS:

From the above discussion it can be seen that the relationships pre-

sented in this report have far reaching significance particularly if confirmatory experiments prove their general character in predicting quantitatively the mass detonation characteristics for any explosive or propellant system. The significance lies in the fact that they can be applied to any explosive system such as vessels, items of ammunition, process etc, where the mass detonation hazard is ever present. Of particular importance is the application of these calculations to the design of new manufacturing plants and storage facilities for the new high-energy propellant missiles. Of immediate interest is the use of these relationships to establish the value of the missile impact sensitivity factor (K) and the output factor (k) for these high energy propellants. Once the various types of propellants have been characterized by these factors, the mass detonation characteristics of systems in which these propellants are utilized, can be determined. This will be a major phase of study in future work in the overall program. This program will also include tests to confirm the accuracy of the proposed relationships, as well as further study of available information relating to vulnerability of explosive systems to fragment impact and mass detonability aimed at refinement of the prediction criteria in terms of such factors as minimum safe distance and shielding between explosive systems for prevention of propagation by fragment impact, and striking probability of fragments.

GLOSSARY OF TERMS

B - constant, designating an explosive and casing material in equation 3a

C - weight of metal casing (lbs)

C' - constant in the fragment distribution formula

d_i - inside diameter of the shell (in)

do - outside diameter of the shell (in)

E - weight of charge (lbs)

$\sqrt{2E'}$ - Gurney energy constant in equation(2)

f - factor depending on E/C in the initial velocity equation

k - constant designating explosive output in equation (1)

K - constant designating explosive sensitivity in equation (6)

m - fragment weight (oz)

M - $m^{1/2}$

M_A - fragment distribution parameter

m_d - mass of smallest fragment which can cause detonation (oz) (when $V_o=V_s$)

N(d) - number of fragments larger than m_d

$N_{(x)}$ - number of fragments larger than (m)

t - thickness of the metal casing (in)

t_m - minimum thickness of the metal casing (in)

V_o - fragment initial velocity (ft/sec)

V_c - critical velocity - striking velocity of a fragment below which "no action" will take place (ft/sec)

GLOSSARY OF TERMS (CONT'D)

V_B - Boundary velocity - striking velocity of a fragment below which no H. O. detonation will occur (ft/sec)

H. O. - high order detonation occurrence

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APPENDIX A

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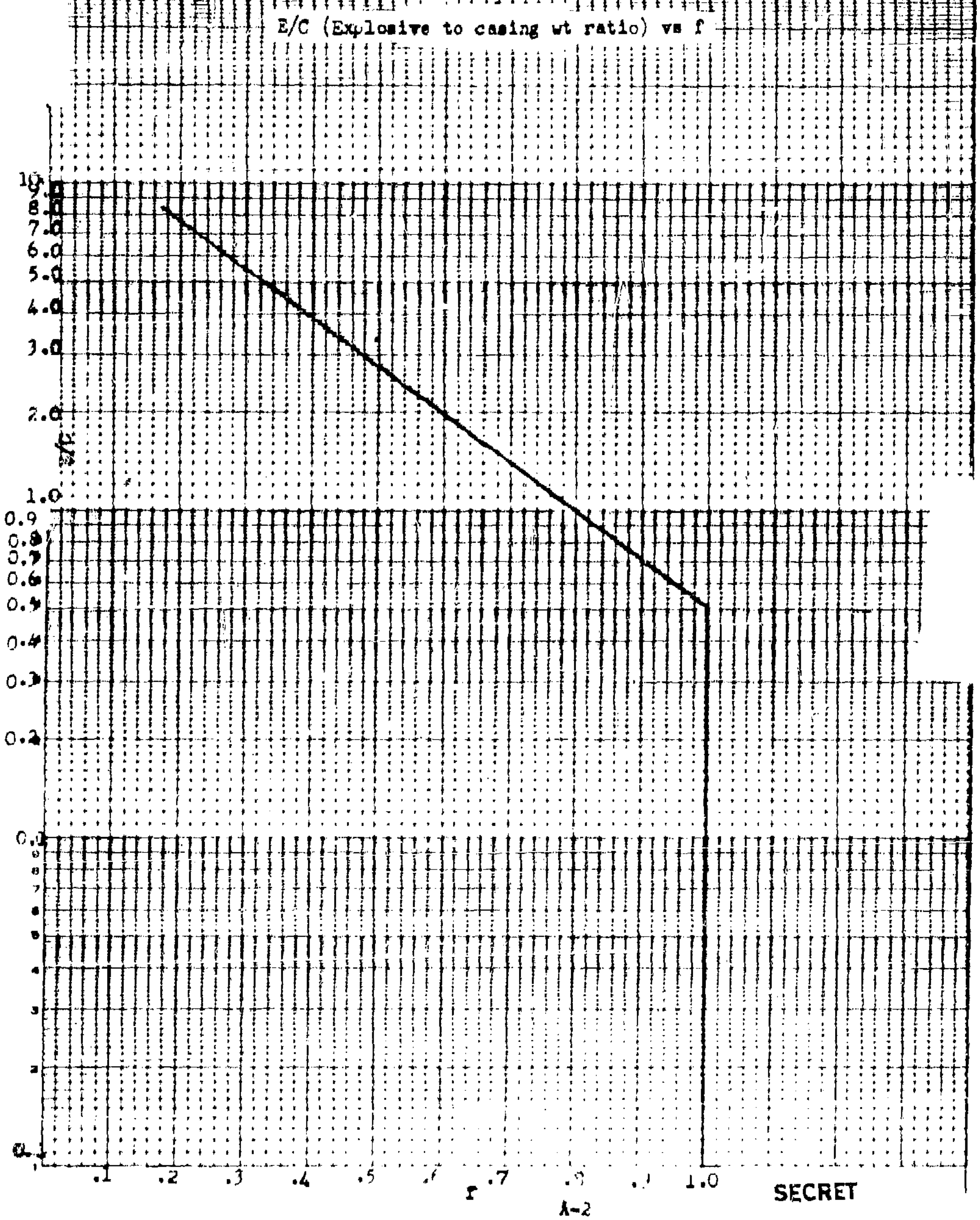

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APPENDIX B

TABLES

TABLE I

Various Explosive Constants used in Calculations

Explosive	$\sqrt{2E'}$ (Ref. 6)	$k/(10^7)$ (Ref. 2)	$K/(10^6)$ (Ref. 3)	B (Ref. 2)
Pentolite	7,550	---	2.780	-----
Comp. B.	7,880	---	-----	-----
RDX/TNT (75/25)	7,850	---	-----	-----
RDX/TNT (70/30)	---	---	3.244	-----
RDX/TNT(60/40)	---	4.4	4.148	27
Torpex	7,950	---	3.554	------
Tetryl	7460	5.2	-----	.24
H-6	7,710	---	-----	-----
TNT	6,950	3.6	16.303	.3
Hexanite	---	3.3	-----	.32
Amatol	---	2.7	14.536	.35

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TABLE II

SUMMARY OF CALCULATED VALUES RELATING TO DETONATION BY MISSILE IMPACT

Item	Drawing No.	Explosive	Section	Vo(f/s)	Vs(f/s)	m (oz)	tm(in.)	E (lbs.)	C (lbs.)	Mass Detonation HO	Md (oz)	Nd Total
76MM M42A1	75-18-33	TNT	Base	2,500	7,600	1.26	0.44	.156	.886	No	-	-
		"	Middle	2,040	5,200	3.3	"	.68	5.9	"	-	-
		"	Nose	1,820	5,300	3.0	"	.10	1.07	"	-	-
		Comp B	B	2,750	4,000	1.2	"	.165	.886	No	-	-
		"	M	2,300	2,700	3.0	"	.72	5.9	"	-	-
		"	N	1,950	2,700	3.0	"	.11	1.07	"	-	-
90MM (M71)	75-18-42	TNT	B	1,470	3,920	4.1	0.45	.103	1.67	No	-	-
		"	M	2,500	3,500	5.25	"	1.40	8.2	"	-	-
		"	N	2,000	4,900	2.6	"	.50	4.75	"	-	-
		Comp B	B	1,750	1,950	4.0	0.45	.11	1.67		-	
		"	M	2,800	1,800	5.0	0.45	1.49	8.2	Yes	2	11
		"	N	2,350	2,500	2.50	0.45	0.55	4.75		-	
105MM M1	75-4-75	TNT	B	1,660	3,100	5.5	.36	.23	3.0	No	-	-
		"	M	2,600	3,200	5.0	.36	2.8	14.2	"	-	-
B-3		"	N	2,920	3,650	3.6	.36	1.87	7.8	"	-	-
		Comp B	B	1,840	1,700	4.7	.36	.25	3.0	Yes	3.7	
		"	M	2,940	1,800	4.5	.36	3.0	14.2	"	1.5	40
		"	N	3,250	2,000	3.05	.36	2.0	7.8	"	1.25	
155MM M107	75-4-99	TNT	B	2,500	2,600	12.0	.562	4.5	25.4	No	-	-
		"	M	3,500	3,600	6.0	.562	4.9	14.8	"	-	-
		"	N	2,900	3,300	7.2	.562	5.7	23.0	"	-	-
240MM M114E1	75-4-92	TNT	B	1,750	1,400	60.	.75	8.7	130	Yes	34	
		"	M	2,700	1,650	40.	.75	19.5	93	"	16.0	20
		"	N	2,900	2,400	20.	.75	24.0	100	"	13.0	
280MM T-122E3	P61726	TNT	B	2,120	1,520	62	1.05	13.7	109	Yes	34	
		"	M	2,900	1,800	47	1.05	37.0	150	"	19	30
		"	N	3,500	2,400	27	1.05	46.0	132	"	13.5	

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TABLE II (CONT'D)

Item	Drawing No.	Explosive	Section	Vo(f/s)	Vs(f/s)	m(oz.)	tm(in.)	E (lbs.)	C (lbs.)	Mass Detonation HO[1]	Md^2(oz)	Nd^3 Total
4.2 in. M329	75-2-453	TNT	B	5,050	4,700	1.25	.18	3.2	3.9	Yes	1.0	4.0
		"	M	5,200	5,100	1.0	"	3.2	3.6	"	.9	
		"	N	4,500	4,900	1.2	"	1.5	2.6			
Rocket-head (3.5 in.) M35A1	82-5207	Comp B		6,500	4,800	.12	.065	1.65	1.2	Yes	.06	17
Rocket-head 4.5 in. M32	82-5-84	Comp B	B	4,000	2,550	1.12	.21	.55	1.52	Yes	.45	
			M	5,250	2,800	1.0	.21	5.0	7.3	"	.28	70
			N	4,750	2,750	1.05	.21	.57	1.06	"	.33	
81MM M56	75-2-283	TNT	B	4,800	7,000	.32	.092	.63	.87	No	--	--
		"	M	6,000	6,900	.33	.092	3.25	2.25	"	--	--
		"	N	4,400	6,700	.37	.092	.48	.85	"	--	--
60MM M49A2	75-2-539	TNT		2,900	6,100	.6	.15	.37	1.5	No	--	--

NOTE:
1. High Order detonation occurrence
2. Md - Smallest fragment which might cause HO detonation
3. Nd - No. of fragments larger than Md

TABLE III

Comparison of Calculated Results with Safety Manual Requirements

Item	Explosive	Mass Detonation Characteristics: Calcul. Results	Mass Detonation Characteristics: Safety Manual
76MM (M42A1)	TNT	No	No
76MM	Comp B	No	No
90MM (M71)	TNT	No	No
90MM	Comp B	Yes	No
105MM (M1)	TNT	No	No
105MM	Comp B	Yes	No
155MM (M-107)	TNT	No	No
240MM (M114E1)	TNT	Yes	No
280MM (T122E3)	TNT	Yes	Yes
4. 2 oz (M329)	TNT	Yes	Yes
Rocket head 3. 5 in. M35A1	Comp B	Yes	Yes
Rocket head 4. 5 in. M32	Comp B	Yes	Yes
81MM M56	TNT	No	Yes
60MM M49A2	TNT	No	No

Note: Yes - Possibility of mass detonation occurrence
No - Nonoccurrence of mass detonation

TABLE IV

Comparison of Calculated Fragmentation Patterns with Experimental Results obtained at Picatinny Arsenal

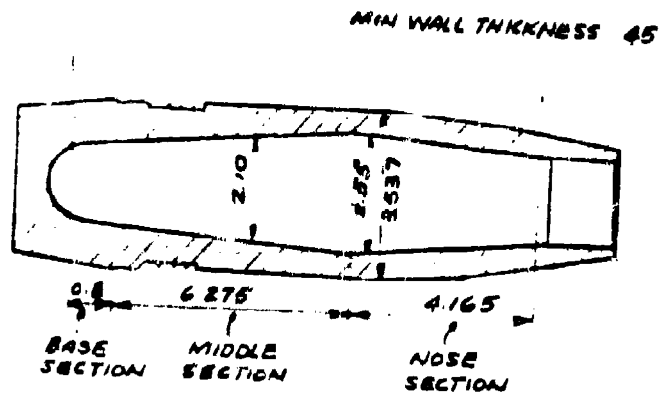
Shell	Explosive	Range (in oz's)	Number of Fragments Calculated	Number of Fragments Experimental
81MM (M 362)	Comp B	over .34	22	9-17
		22-.34	35	20-25
155MM M107	TNT	17-5.7oz	120	160
		over 5.7	21	30-40
105MM M1	TNT	34-1.7	255	300
	"	1.7-5.7	40	30
	Comp B	34-1.7	300	250
		1.7-5.7	30	25-40
90MM M71	Comp B	34-1.7	155	200
		over 1.7	23	20-30

APPENDIX C

APPENDIX C

SAMPLE CALCULATION

Basis: 90MM M71 HE Shell
Drawing No.: 75-18-42



I Base Section: (TNT loaded)

Average d_i = 1.60 inches
Average do = 3.54 inches
Average t = 0.97 inch
Length = 0.80 inch
Total Volume = $0.80\ (3.54)^2\ (0.785) = 7.85$ cu. inches
Volume of Explosive = $0.8\ (1.6)^2 (0.785) = 1.85$ cu. inches
Volume of Casing = 7.85 - 1.85 = 6.00 cu. inches
Density of Explosive = 1.55 (0.036) = 0.0558 lbs/cu. inch
Weight of Explosive (E) = 1.85 (0.0558) = 0.103 lbs.
Density of Casing = 7.8 (0.036) = 0.281 lbs/cu. inch
Weight of Casing (C) = 6 (0.281) = 1.67 lbs.

$$\text{Initial Fragment Velocity } (V_o) = \sqrt{\frac{E}{C}\ (kf)}$$

$$= \sqrt{\frac{0.103}{1.67}\ (3.6 \times 10^7)\ (1)}$$

$$= 1470 \text{ ft./sec.}$$

Fragment Distribution Parameter $(M_A) = Bt^{5/6}d_i^{1/3}\left(1+\frac{t}{d_i}\right)$

$$= 0.3(0.97)^{5/6}(1.60)^{1/3}\left(1+\frac{0.97}{1.60}\right)$$

$$= 0.54$$

Fragment Parameter Distribution Constant $(C') = {}^{C}/{2M_A^3}$

$$= \frac{1.67\ (16)}{2\ (0.54)^3} = 84$$

(M_A & C' are both expressed on the basis of inches and ounces.)

<u>Calculation of Largest Fragment</u>

$$\ln N_x = \ln(C'M_A) - \frac{M}{M_A}$$

Let $N_x = 1$; then $\ln N_x = 0$

$$M = M_A \ln(C'M_A)$$
$$= 0.54 \ln(84 \times 0.54)$$
$$= 2.0$$
$$m = M^2 = 4\text{oz.}$$

Boundary Velocity (V_s) = $\dfrac{Ke^{5.37\ (tm/m^{1/3})}}{m^{2/3}\left(1+3.3\ \frac{tm}{m^{1/3}}\right)}$

<u>Note:</u> tm = overall minimum shell thickness

$$Vs = \frac{16.303\ (10^6)e^{5.37(0.45/1.58)}}{2.5\left(1+3.3\ \frac{0.45}{1.58}\right)}$$

= 3920 ft./sec. (this value may also be obtained from Graph 2a, Appendix D)

Since Vs > Vo no High Order detonation will take place.

II Middle Section (Composition B loaded)

V_o = 2,800 ft./sec.
V_s = 1,800 ft./sec.
(calculated same way as outlined above)
$V_s < V_o$, therefore there exists a possibility of high order detonation occurrence.

Calculate the smallest fragment which will cause a high order detonation due to impact by setting $V_o = V_s$. Thus V_s = 2800
Find from figure 5a mass of a fragment corresponding to V_s = 2,800 and t_m = 0.45. Thus m = 2 oz

Calculate the number of fragments ($N_{(x)}$) which might cause a high order detonation in the acceptor explosive using formula

$$\ln N_{(x)} = \ln (CM_A) - \frac{M}{M_A}$$

$$\ln N_{(x)} = \ln (1,170 \times .377) - \frac{1.42}{.377}$$

$$\underline{N_{(x)} = 11}$$

APPENDIX D

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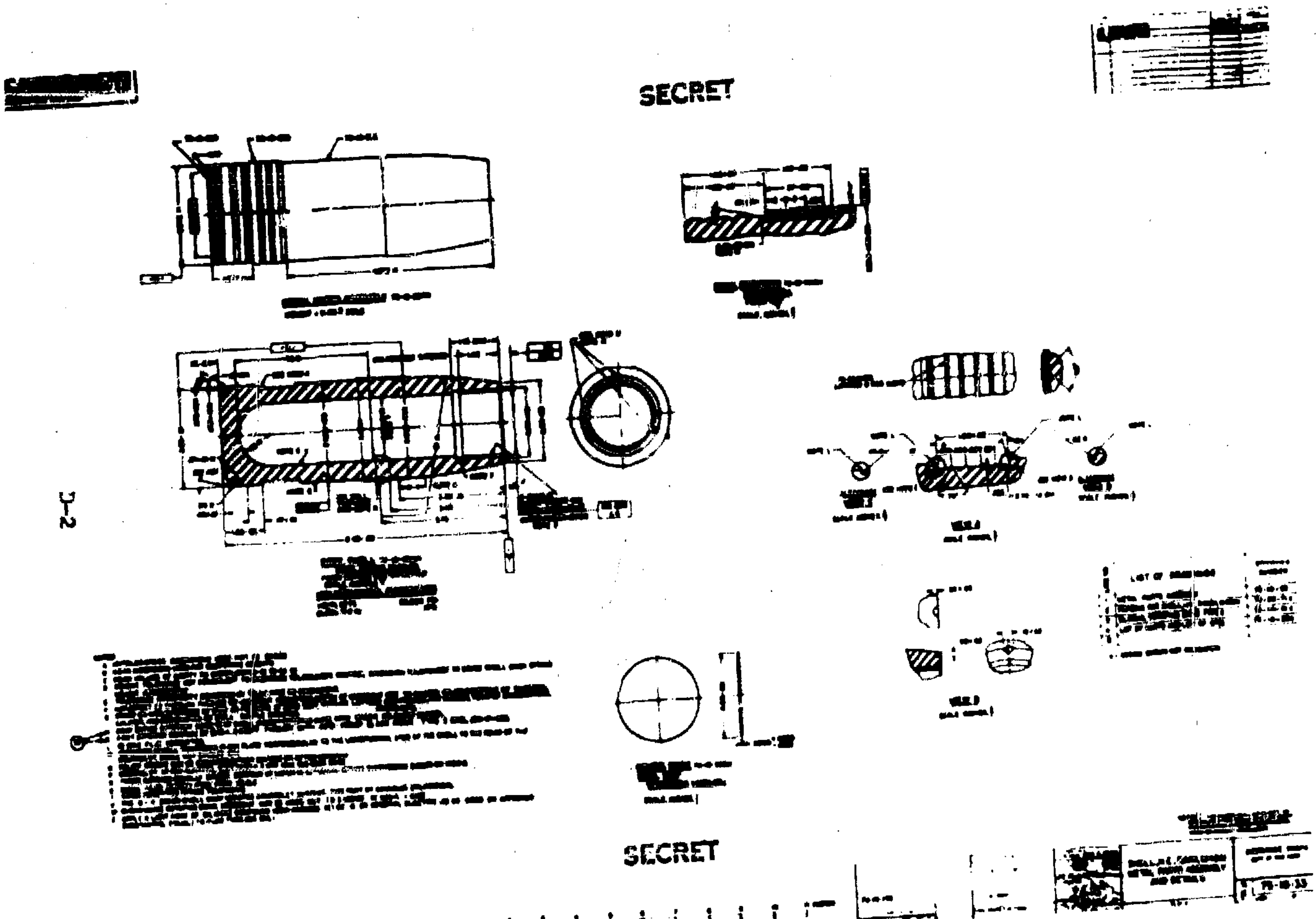

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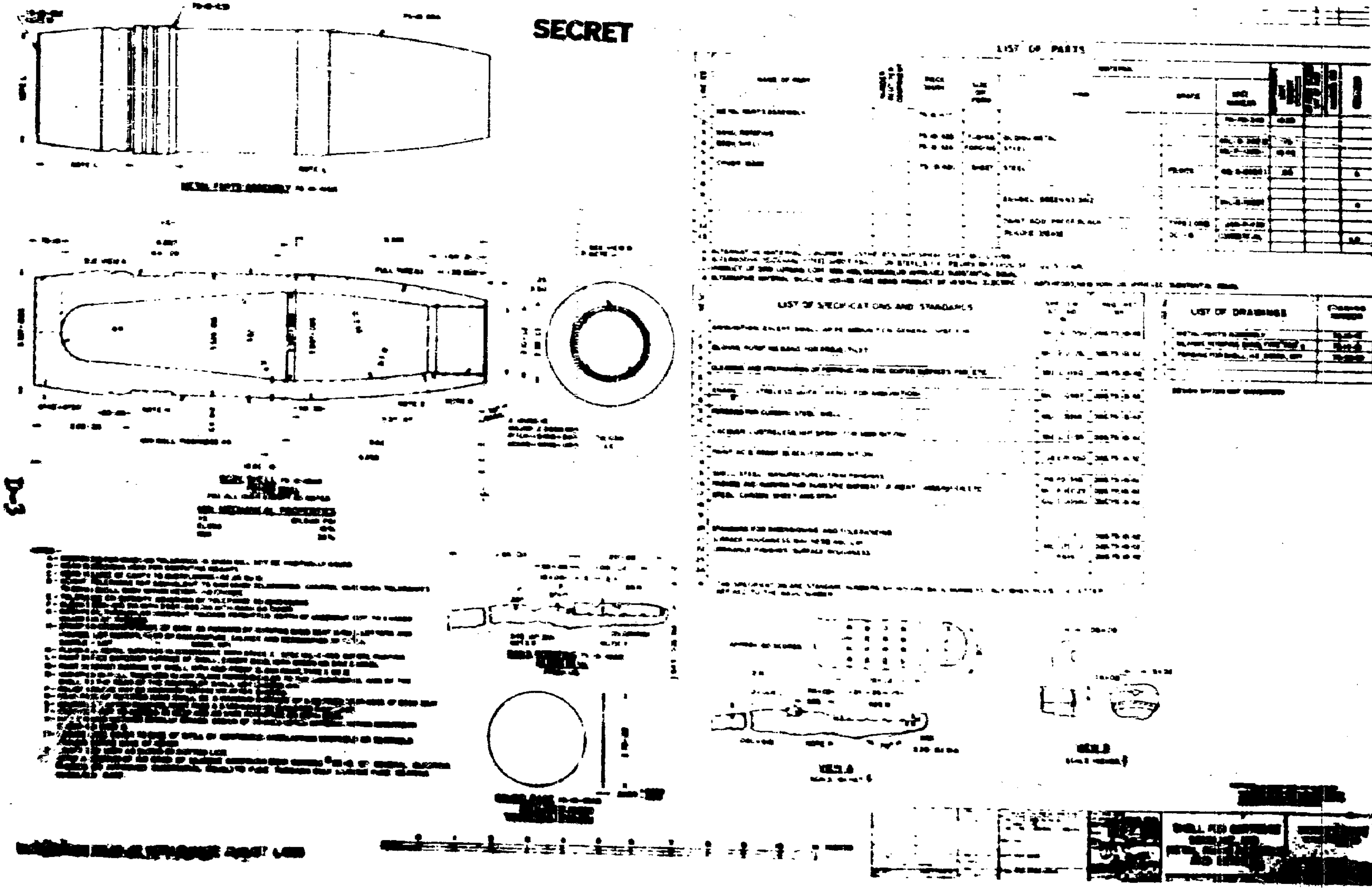
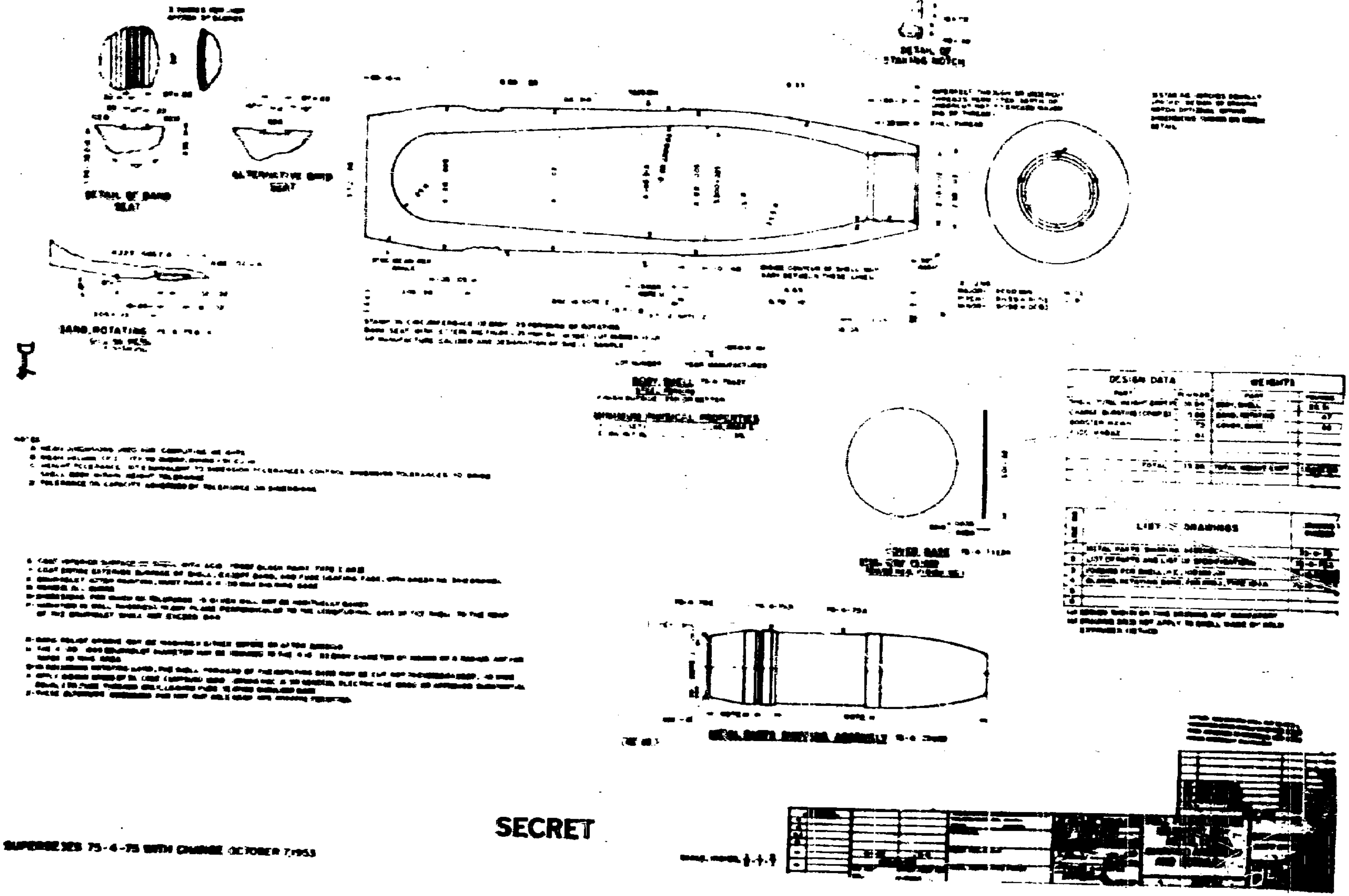
SUPERSEDES 75-18-33 WITH CHANGE FEBRUARY 23, 1960


SECRET
LIST OF PARTS
LIST OF SPECIFICATIONS AND STANDARDS
LIST OF DRAWINGS

SECRET

SECRET



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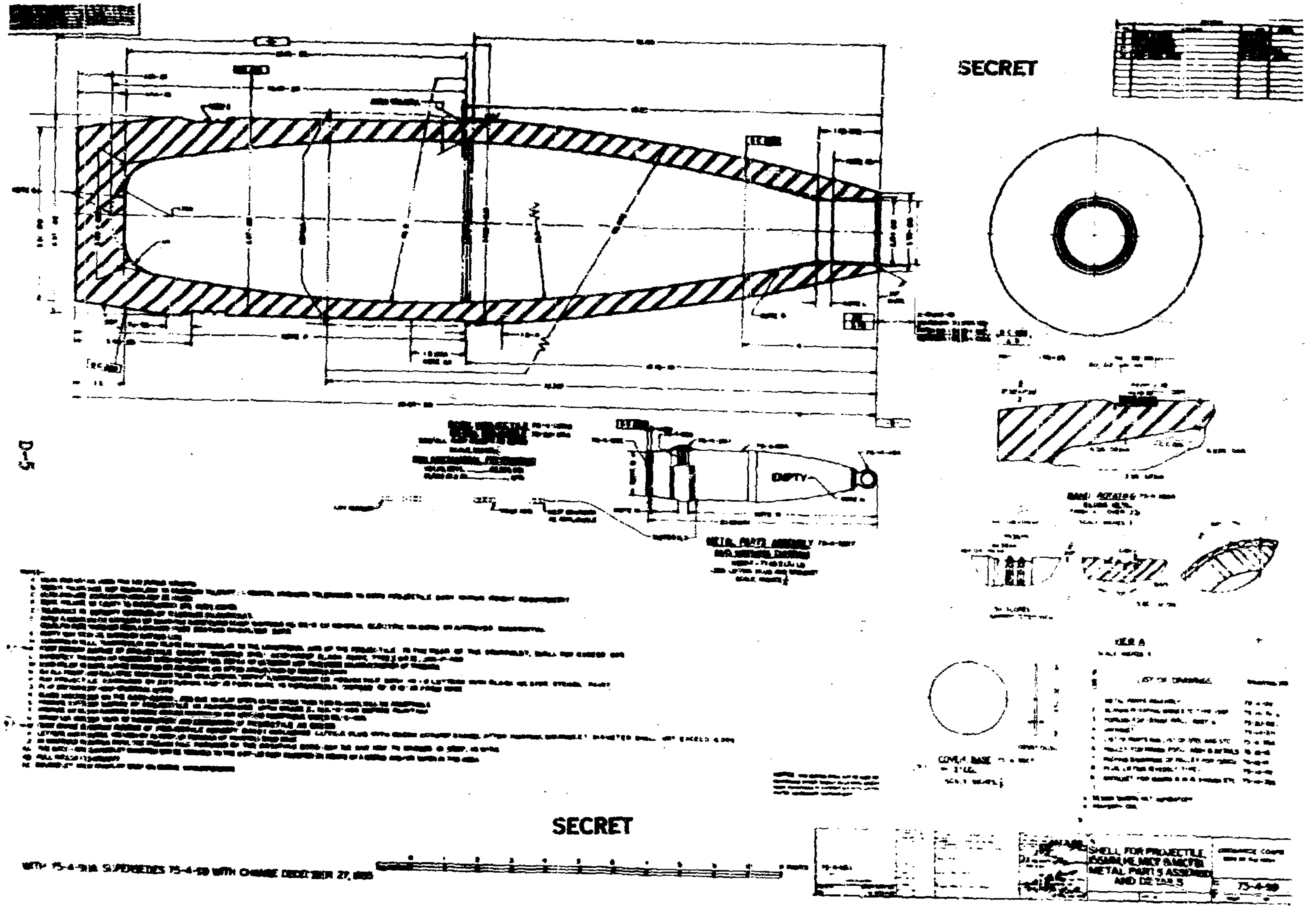
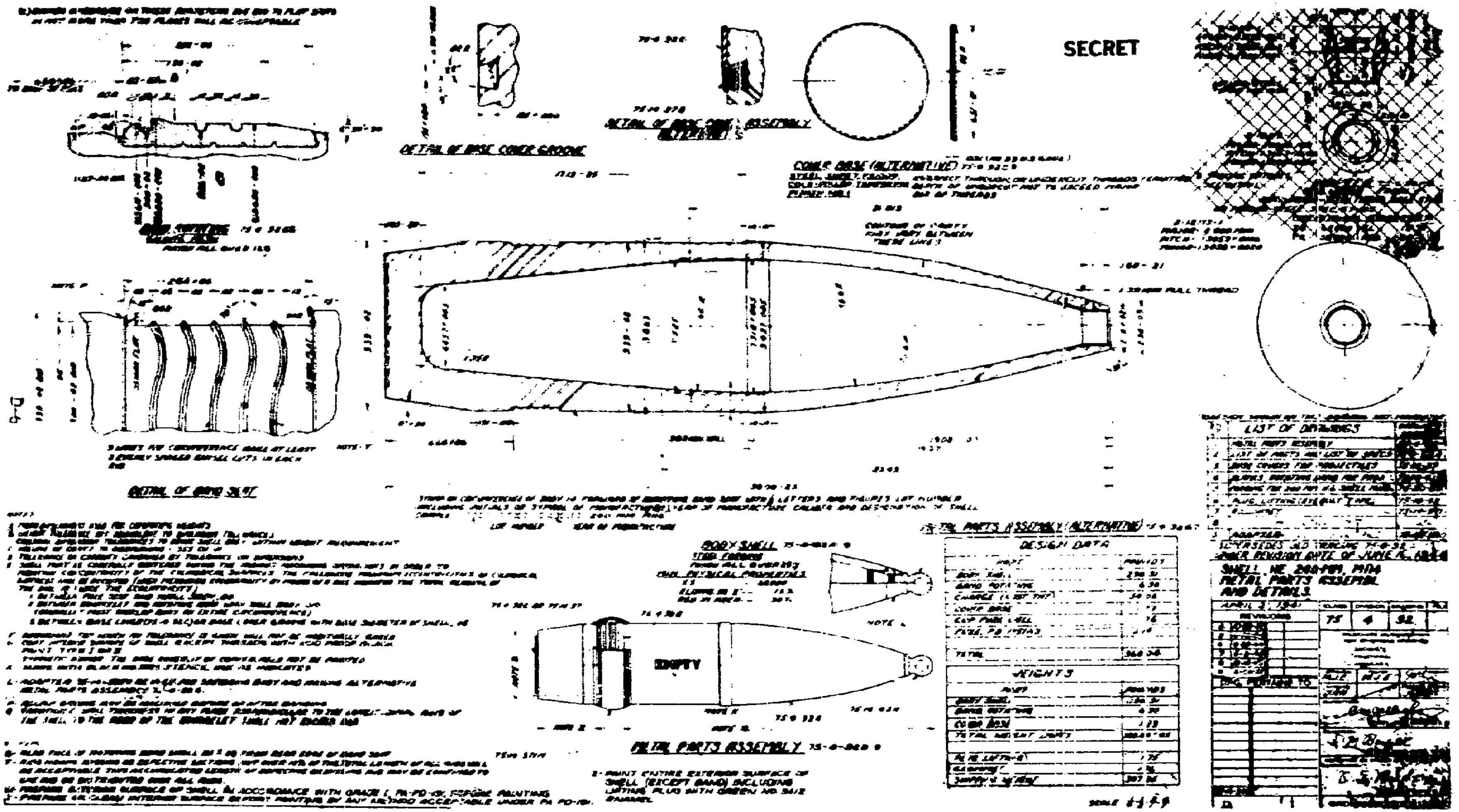
SUPERSEDES 75-4-75 WITH CHANGE OCTOBER 7, 1953


SECRET
EMPTY
COVER, BASE
SHELL FOR PROJECTILE
METAL PARTS ASSEMBLY AND DETAILS
75-4-59
SECRET
WITH 75-4-59A SUPERSEDES 75-4-59 WITH CHANGE DECEMBER 27,

SECRET



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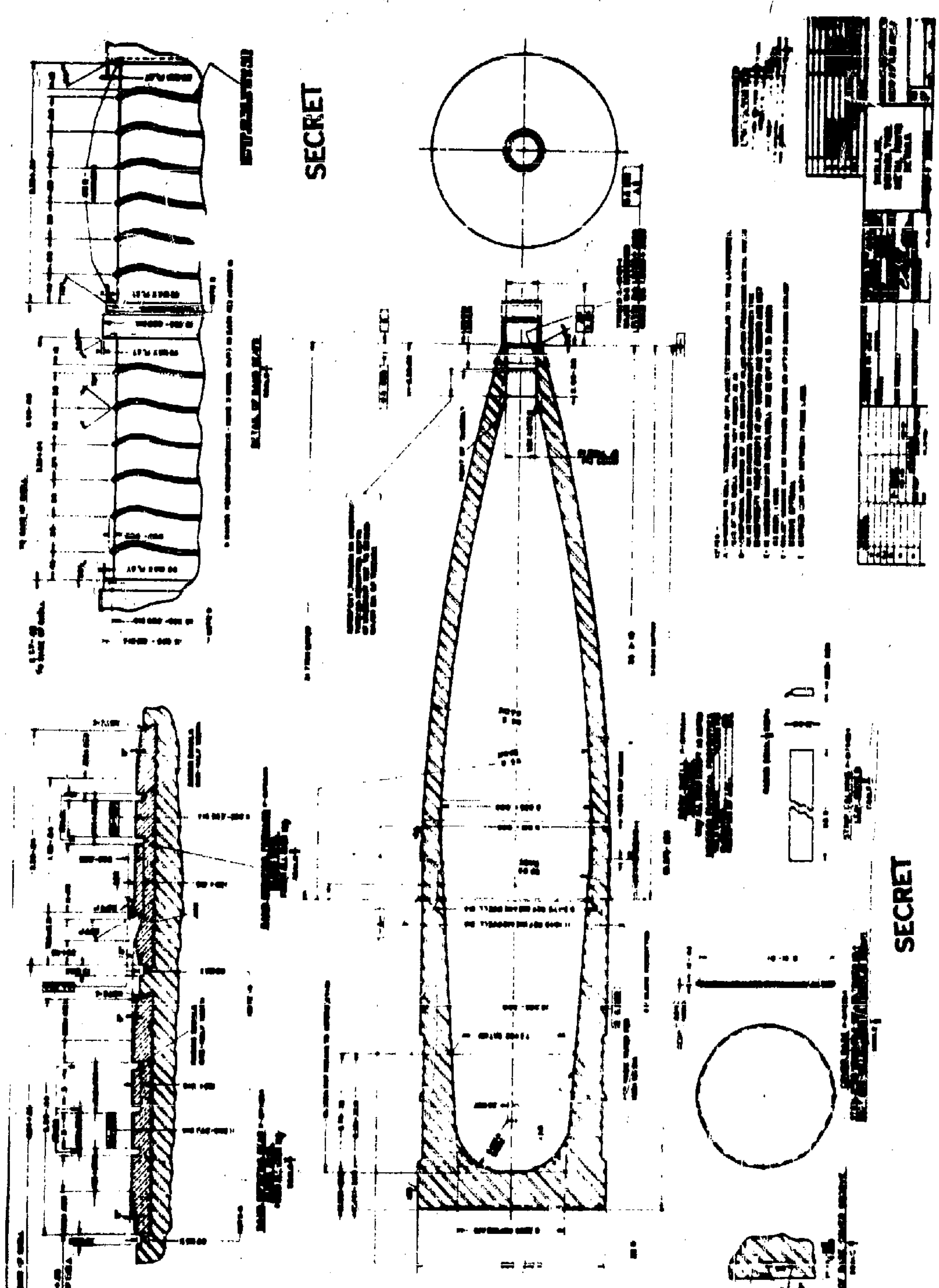
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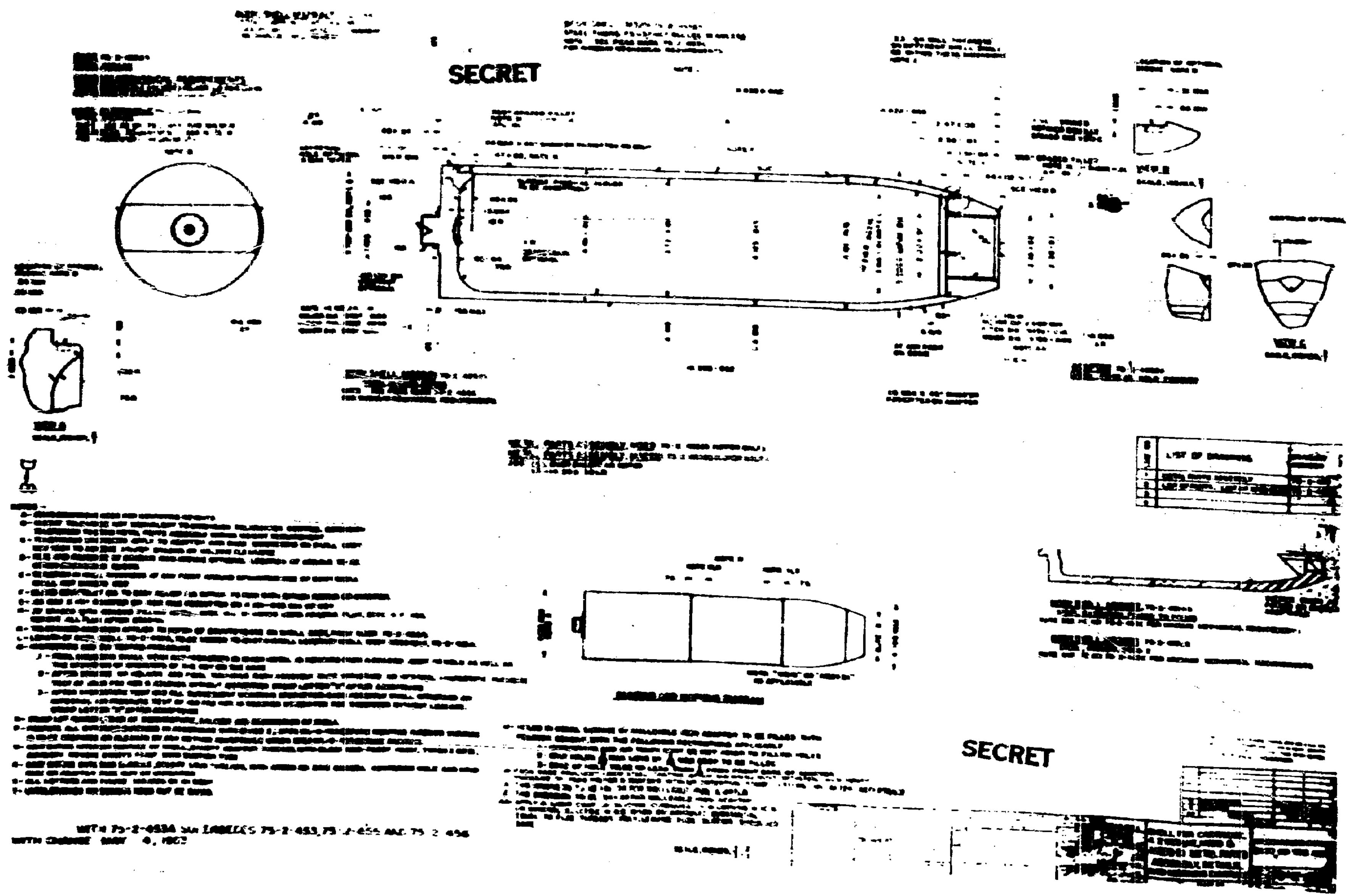
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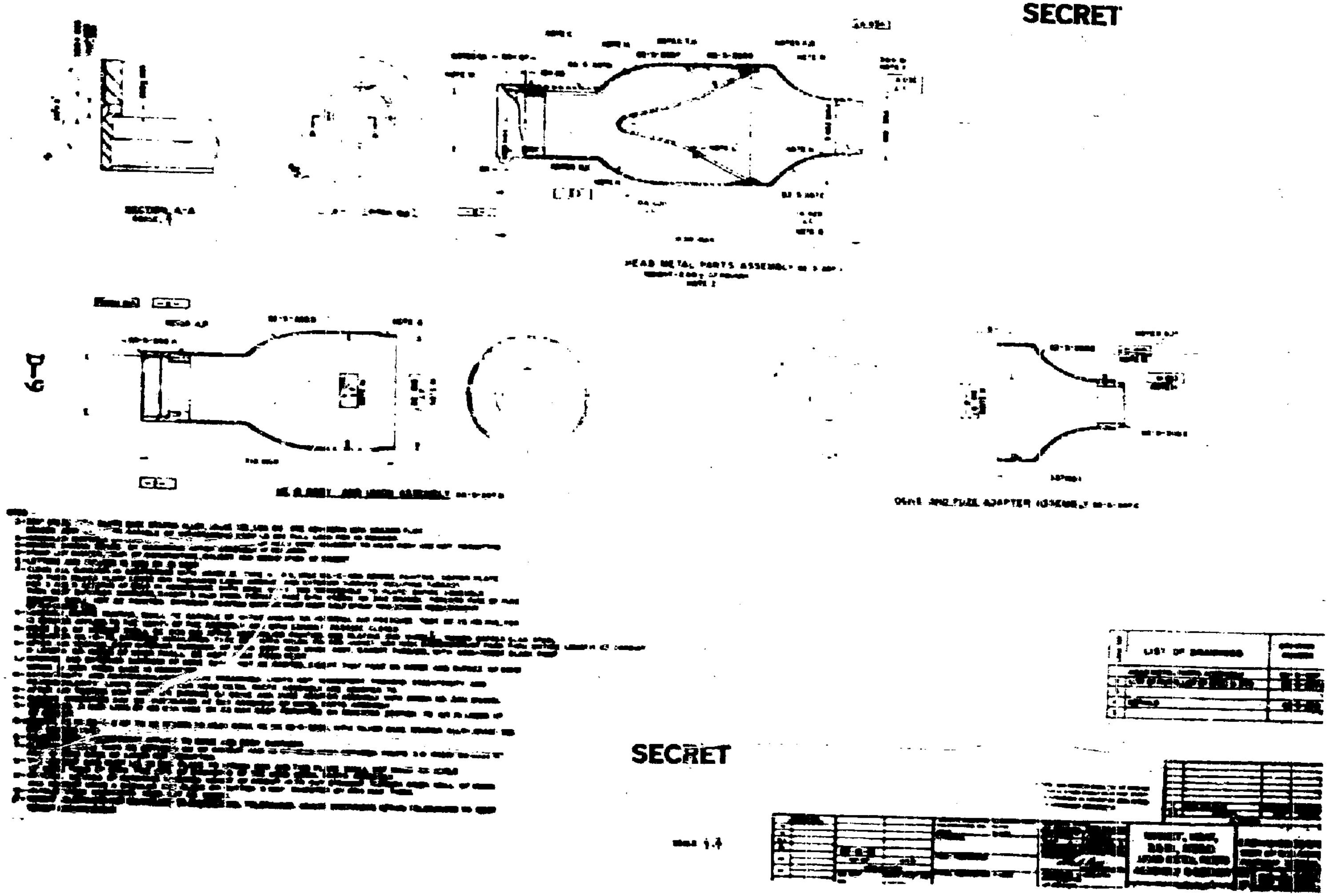

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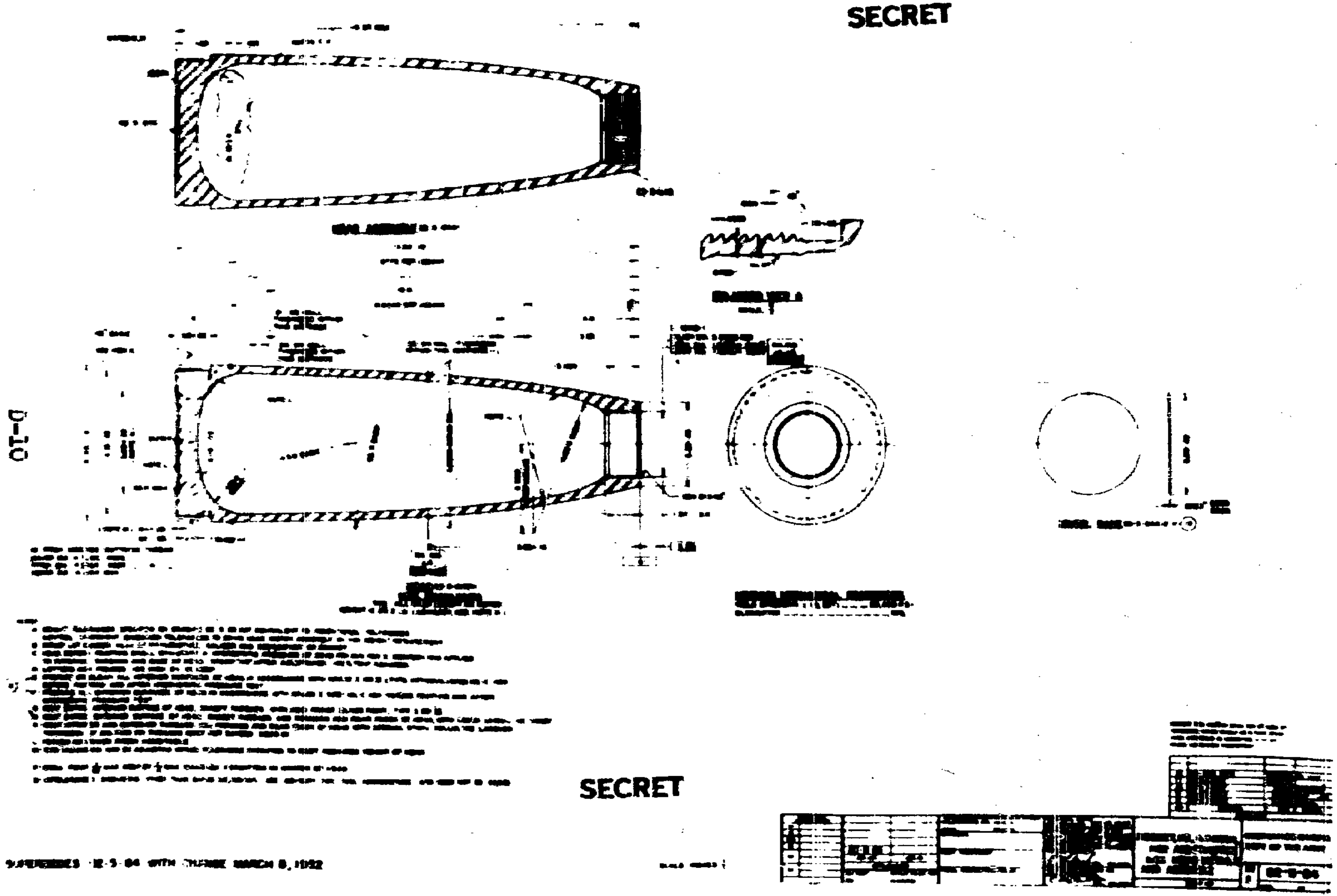

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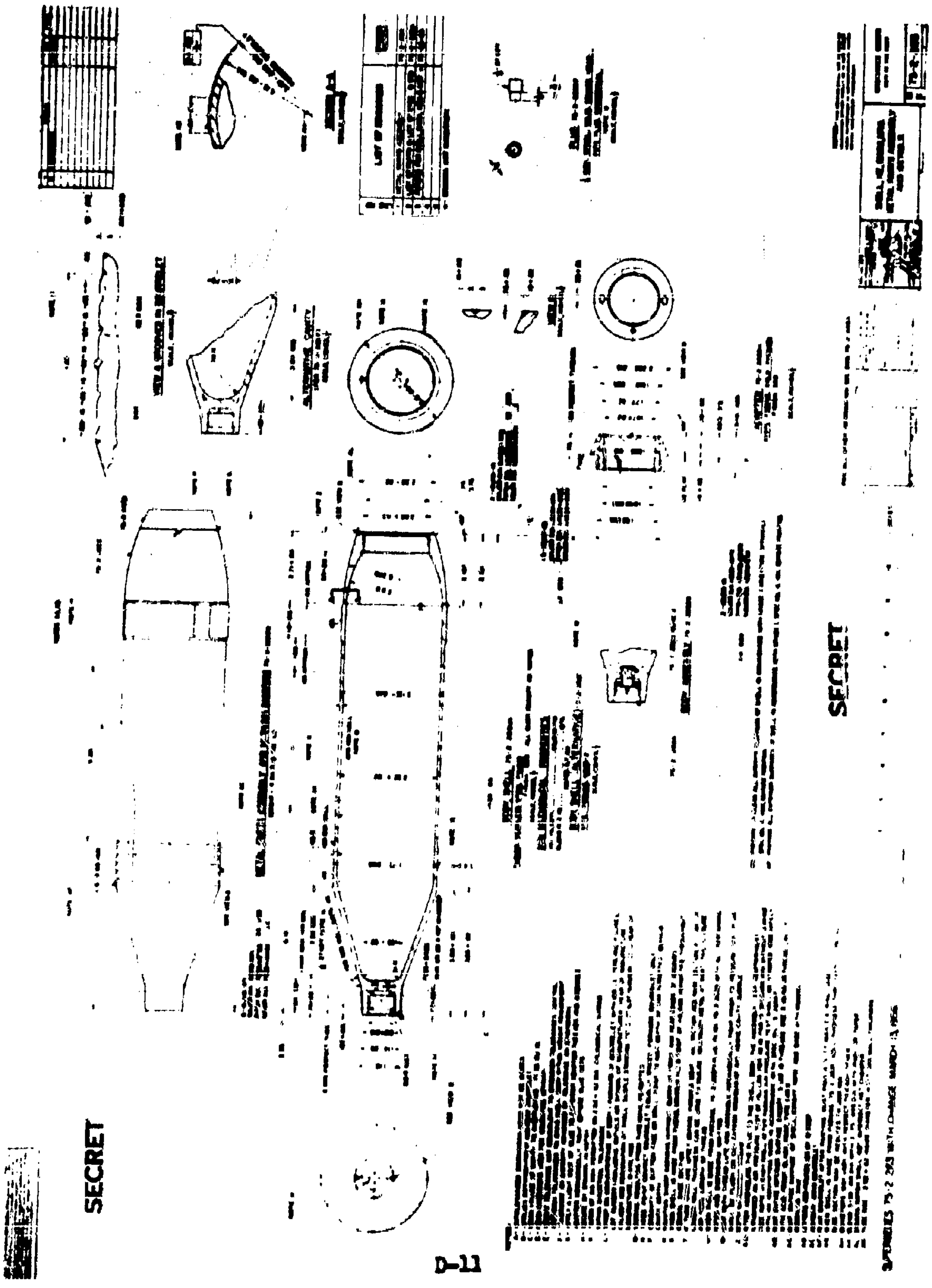
SUPERSEDES 12-5-84 WITH CHANGE MARCH 8, 1982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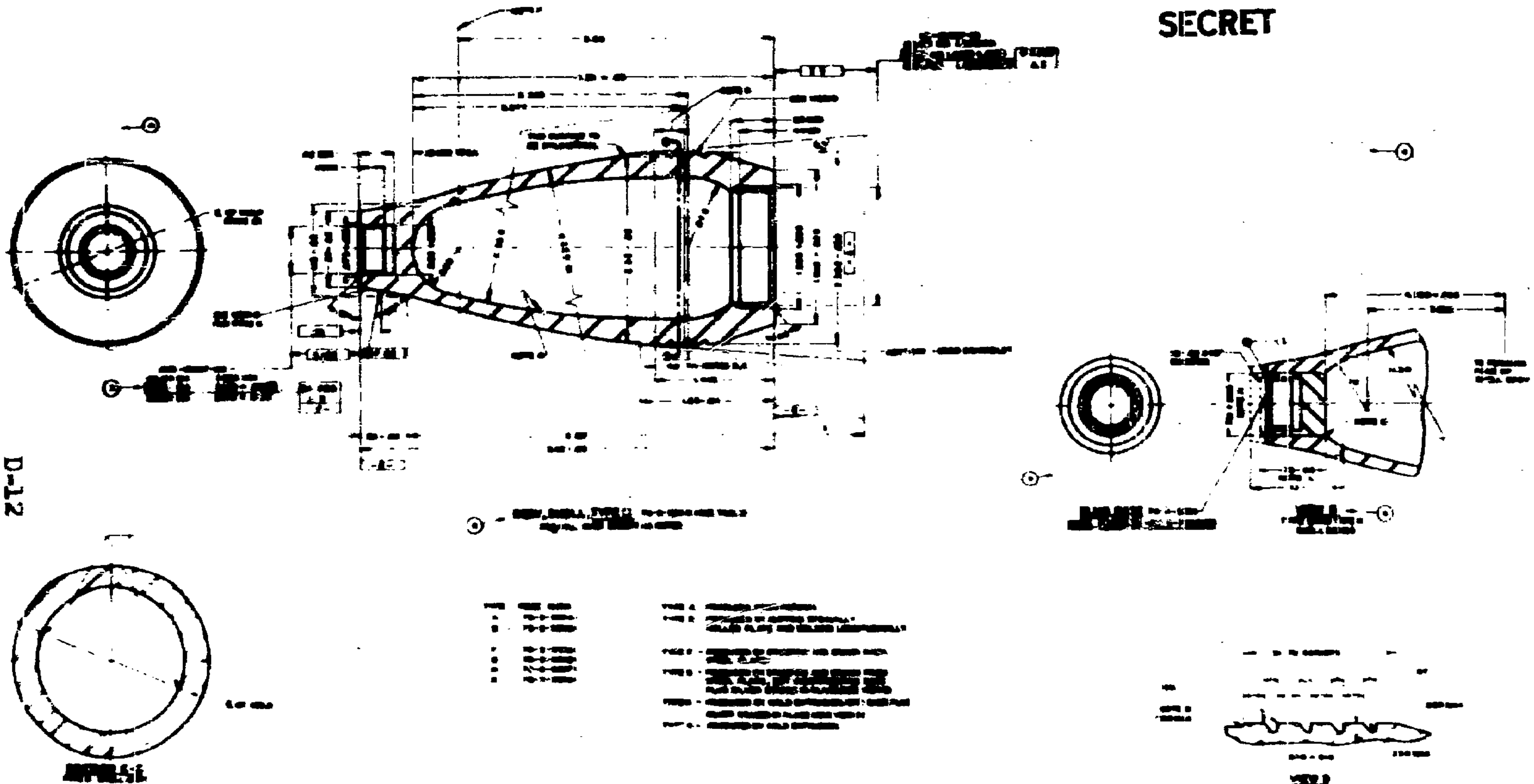

D-12

SECRET

SUPERSEDES 75-2-288 IN PART WITH CHANGE AUG 4, 1954

APPENDIX E

Graphs -- Relating to Boundary Velocity, Fragment Mass and Casing Thickness

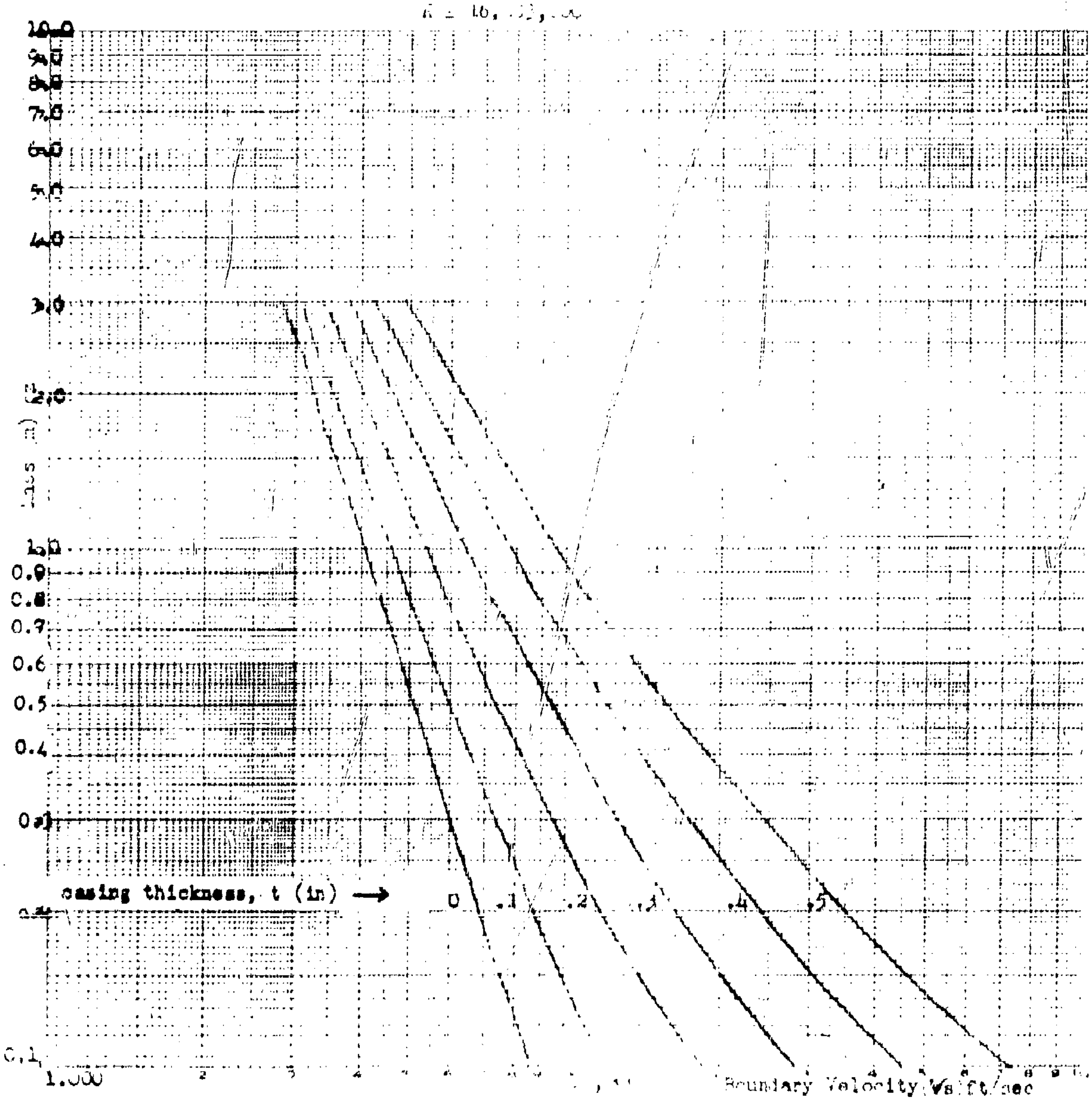

Fig. 1 TNT [illegible] Range

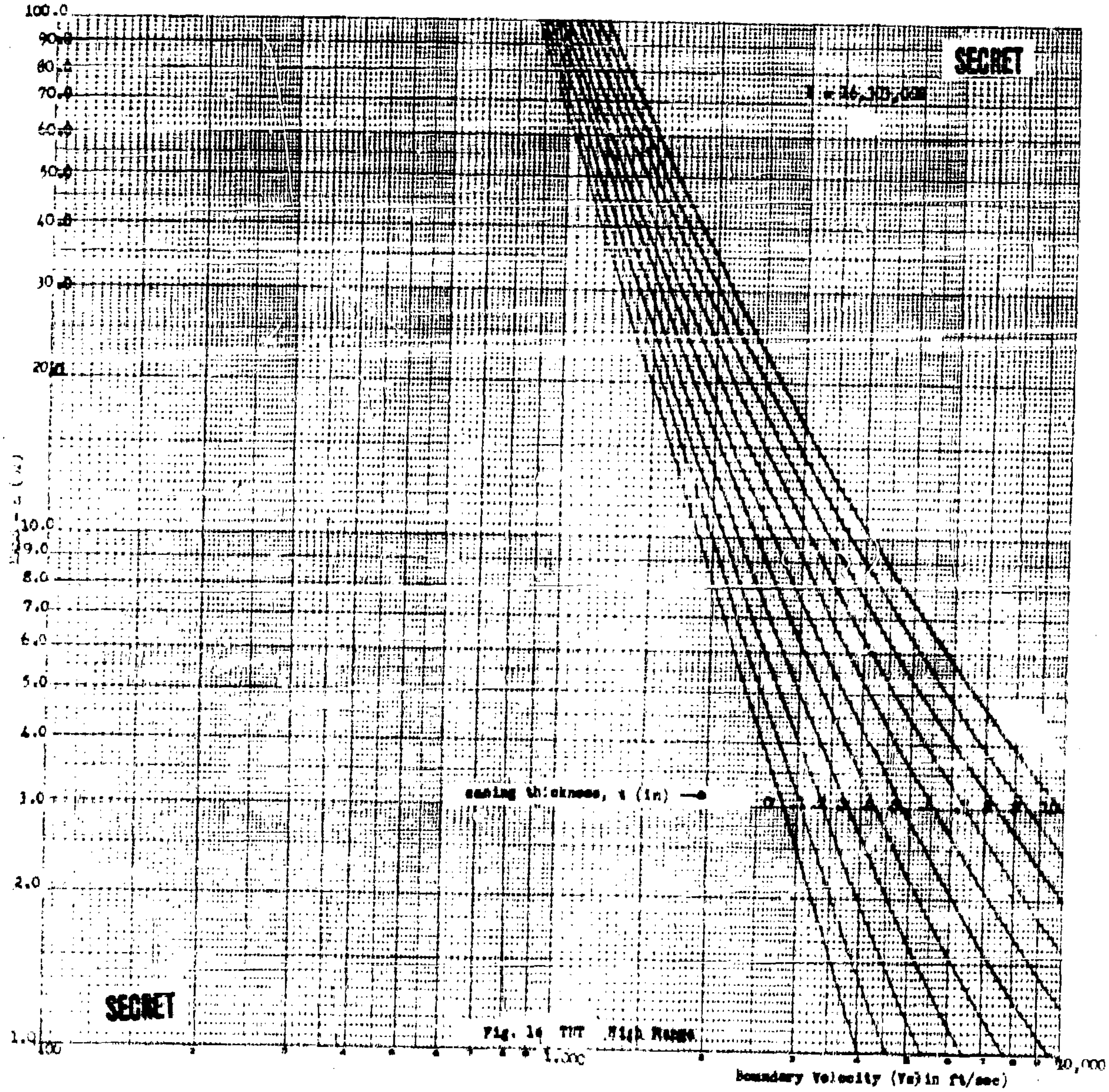

Fig. 14 TNT High Range

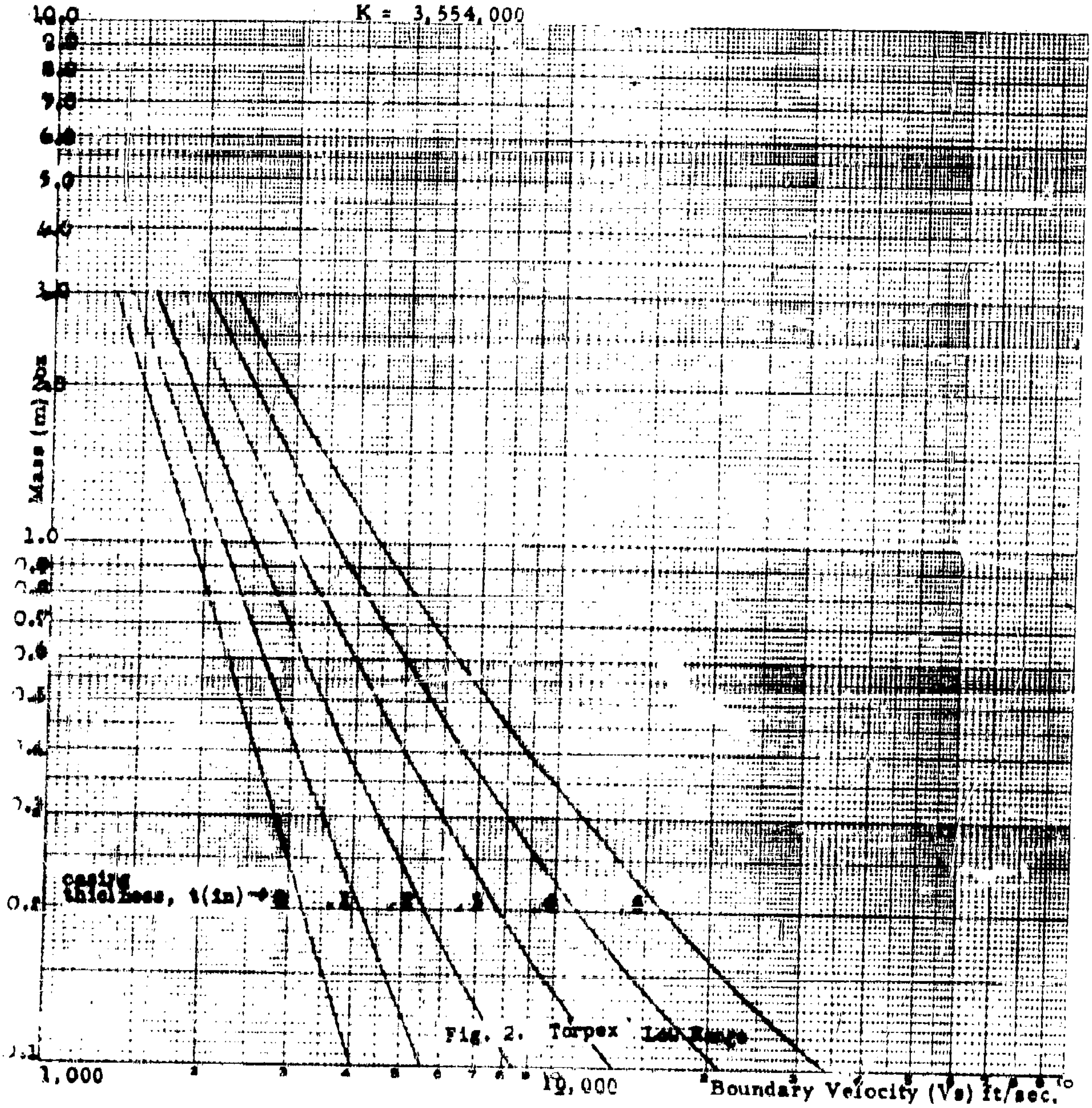

Fig. 2. Torpex Low Range

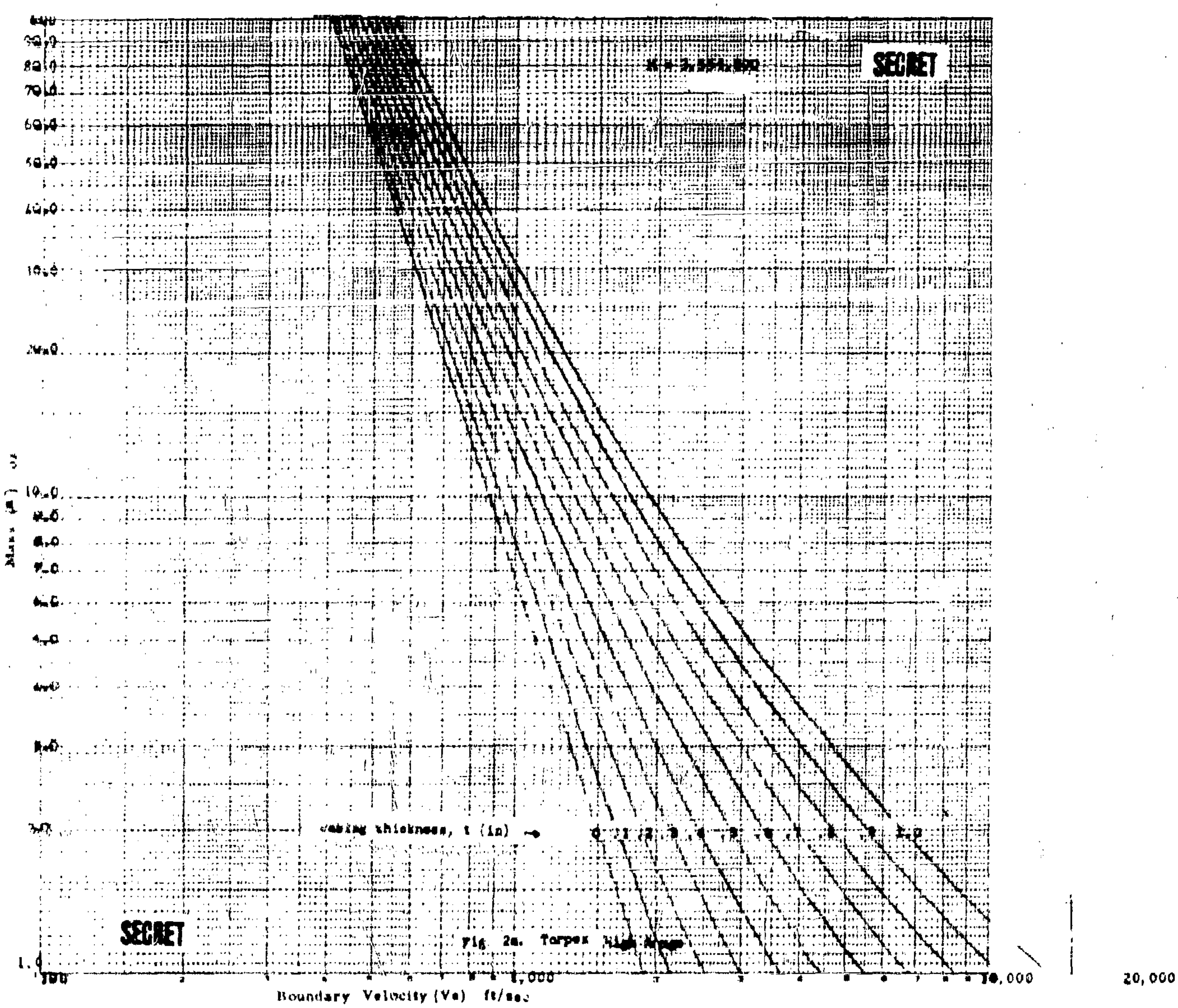

Fig. 2a. Torpex [illegible]

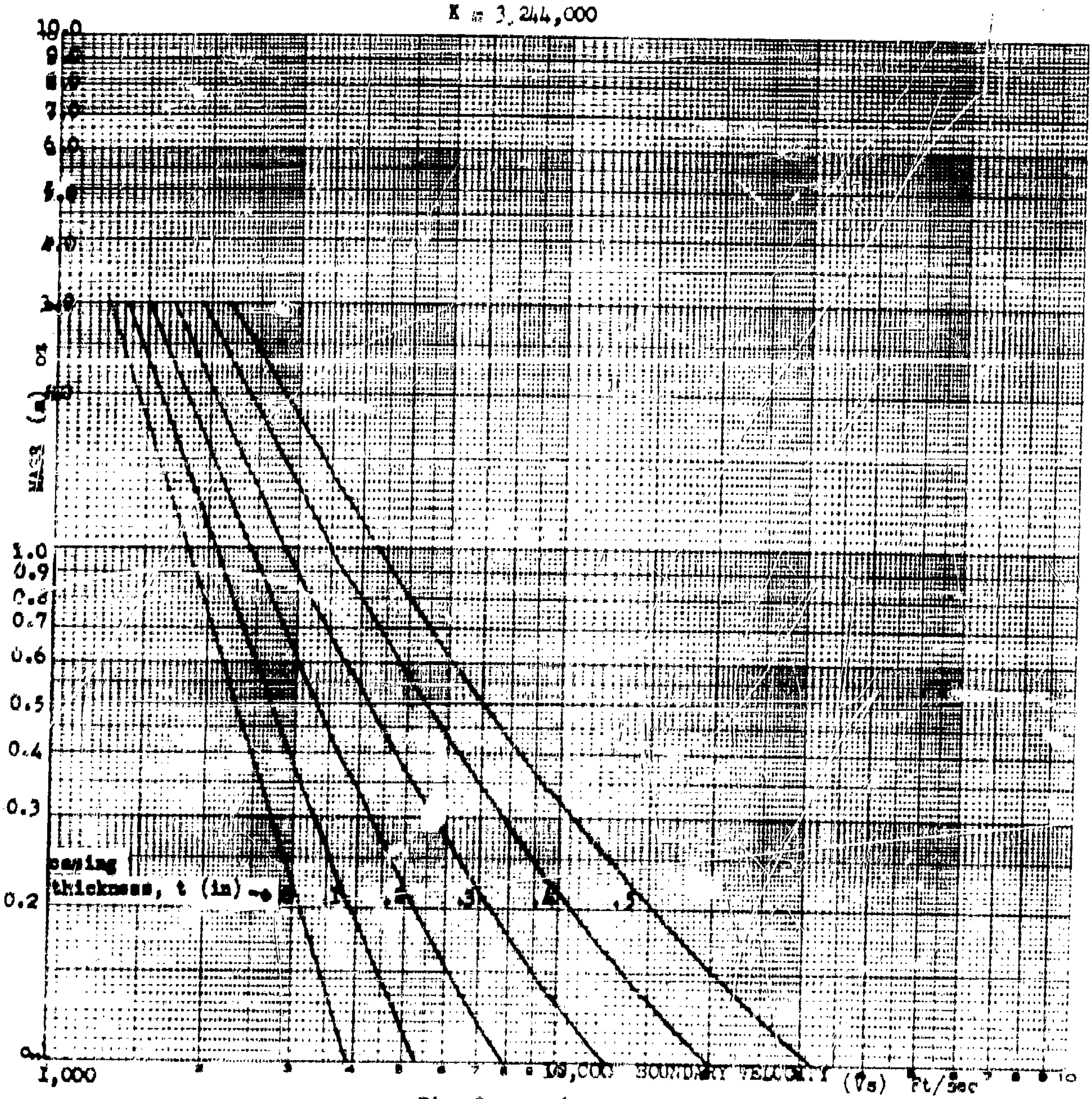

Fig. 3. RDX/TNT 70/30 Low Range

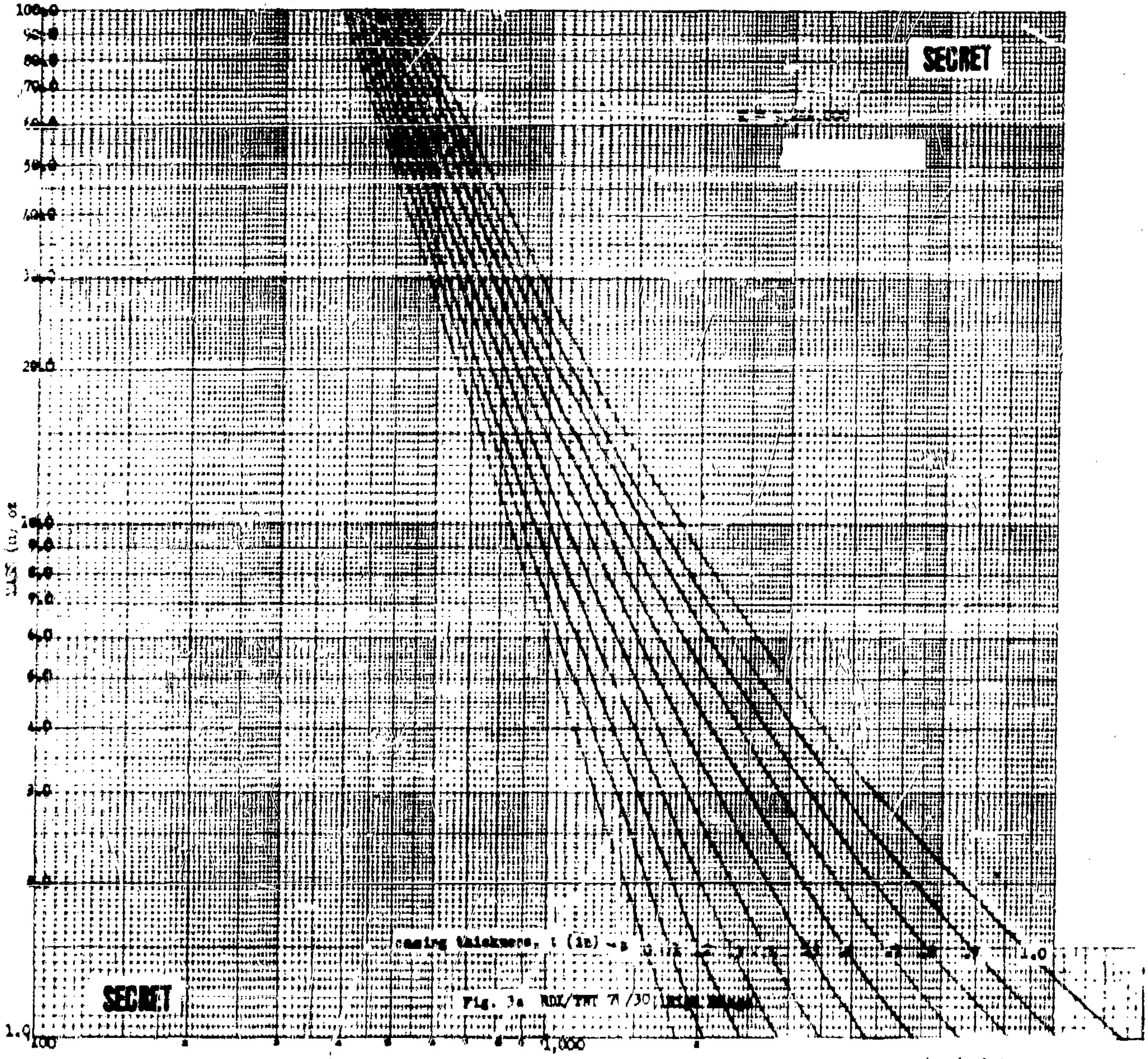

Fig. 3a RDX/TNT 70/30

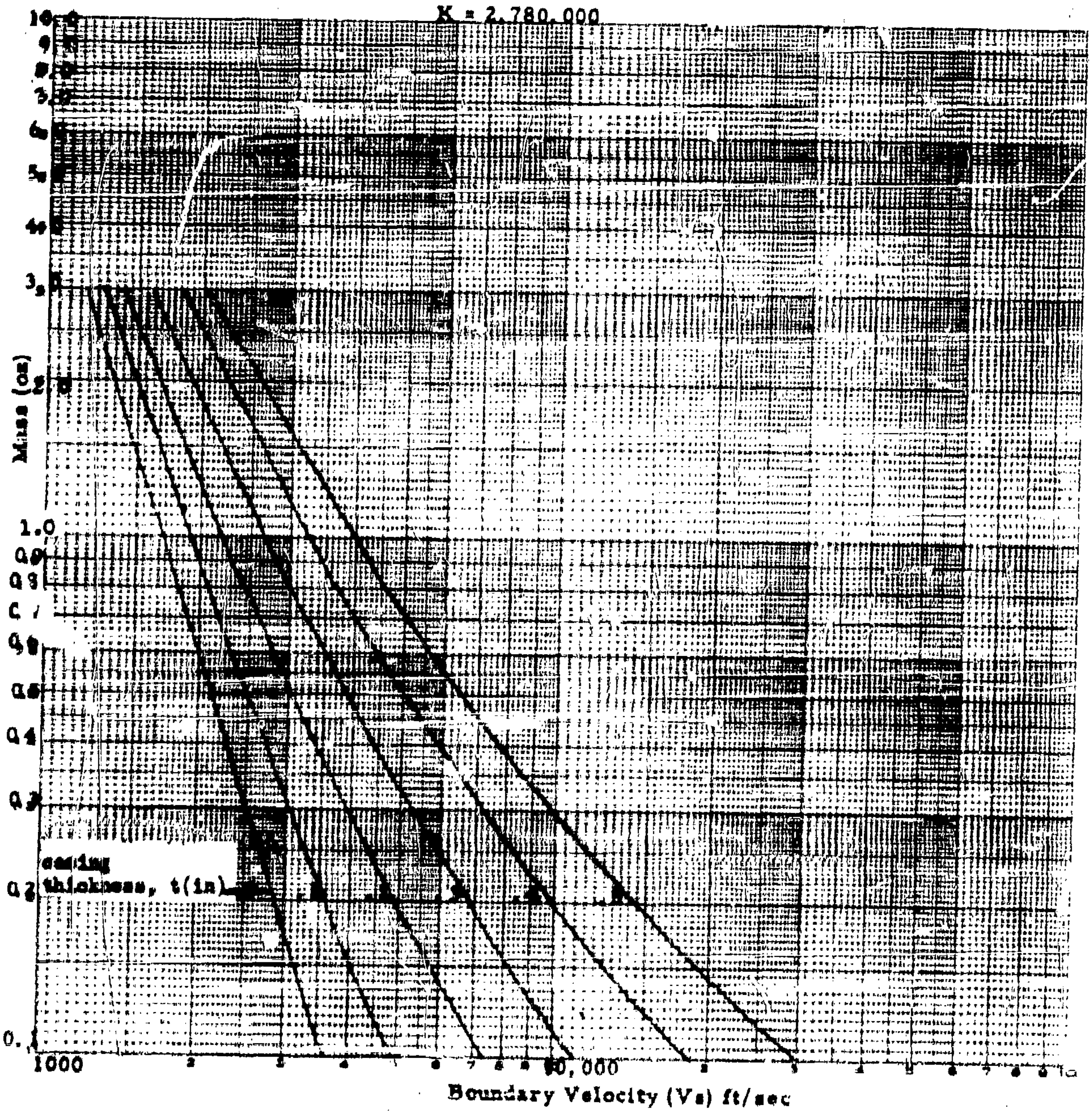

Fig. 4. Pentolite Low Range

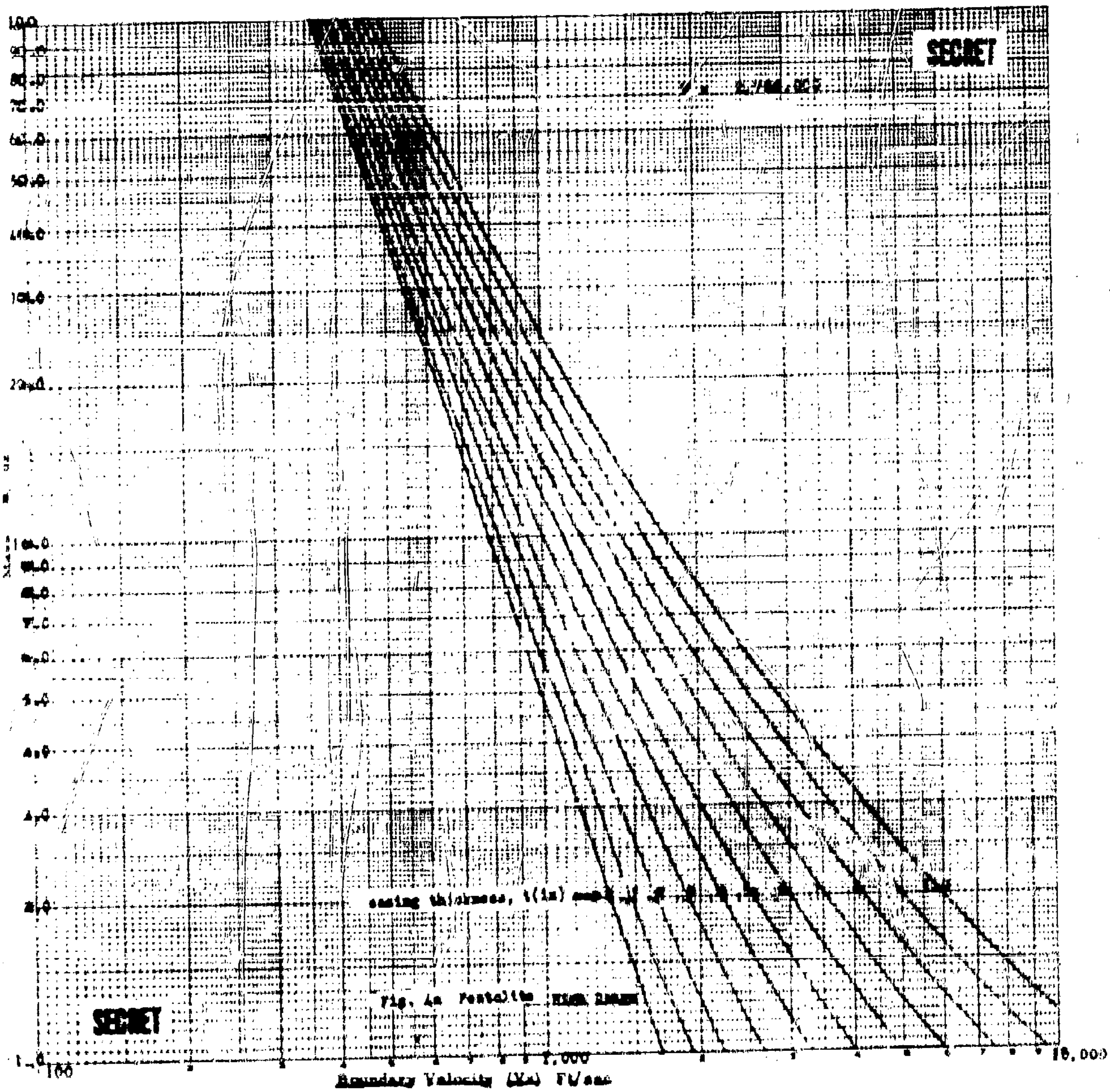

Fig. 4a Pentolite

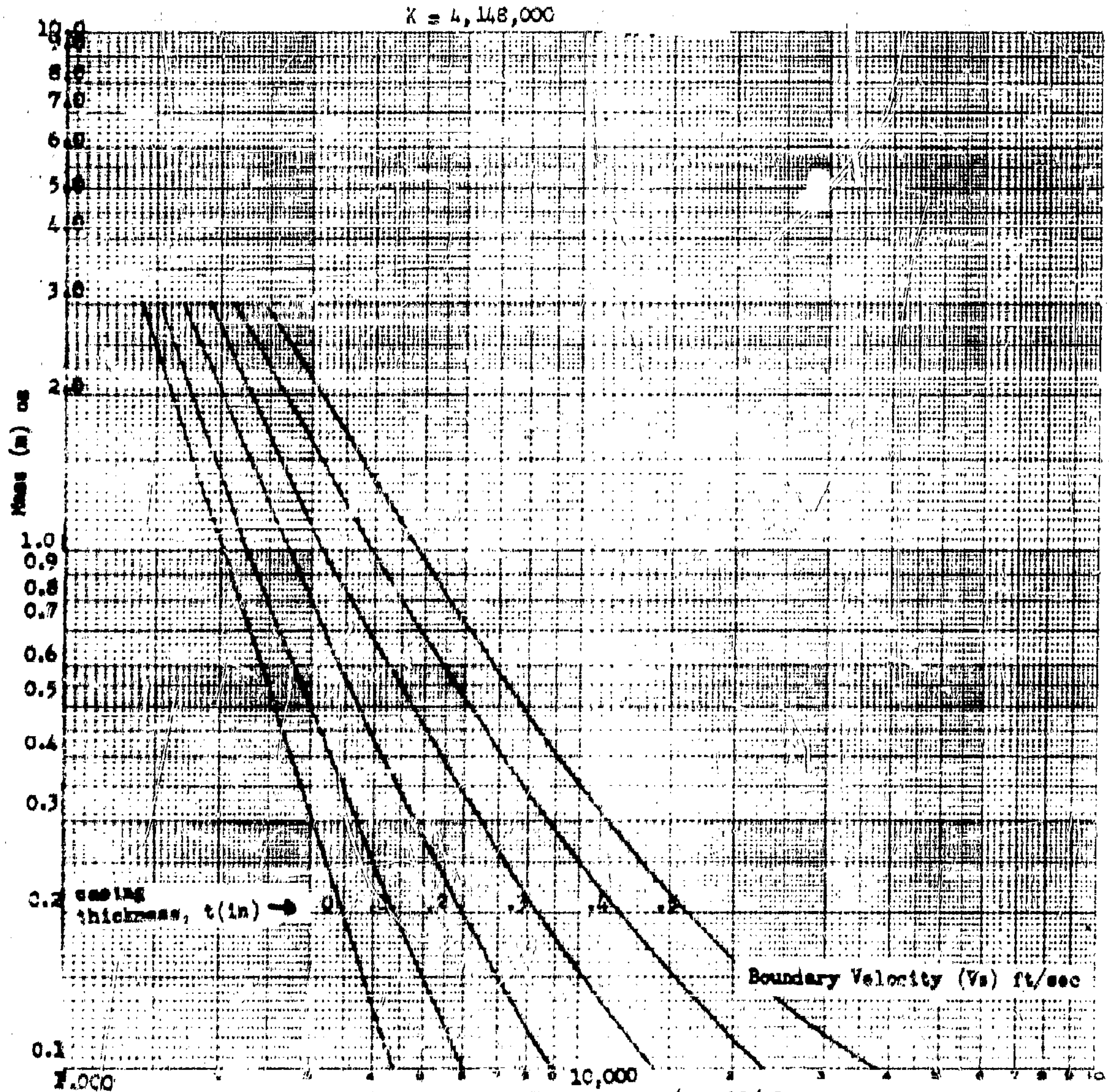

Fig. 5. RDX/TNT 60/40 Low Range

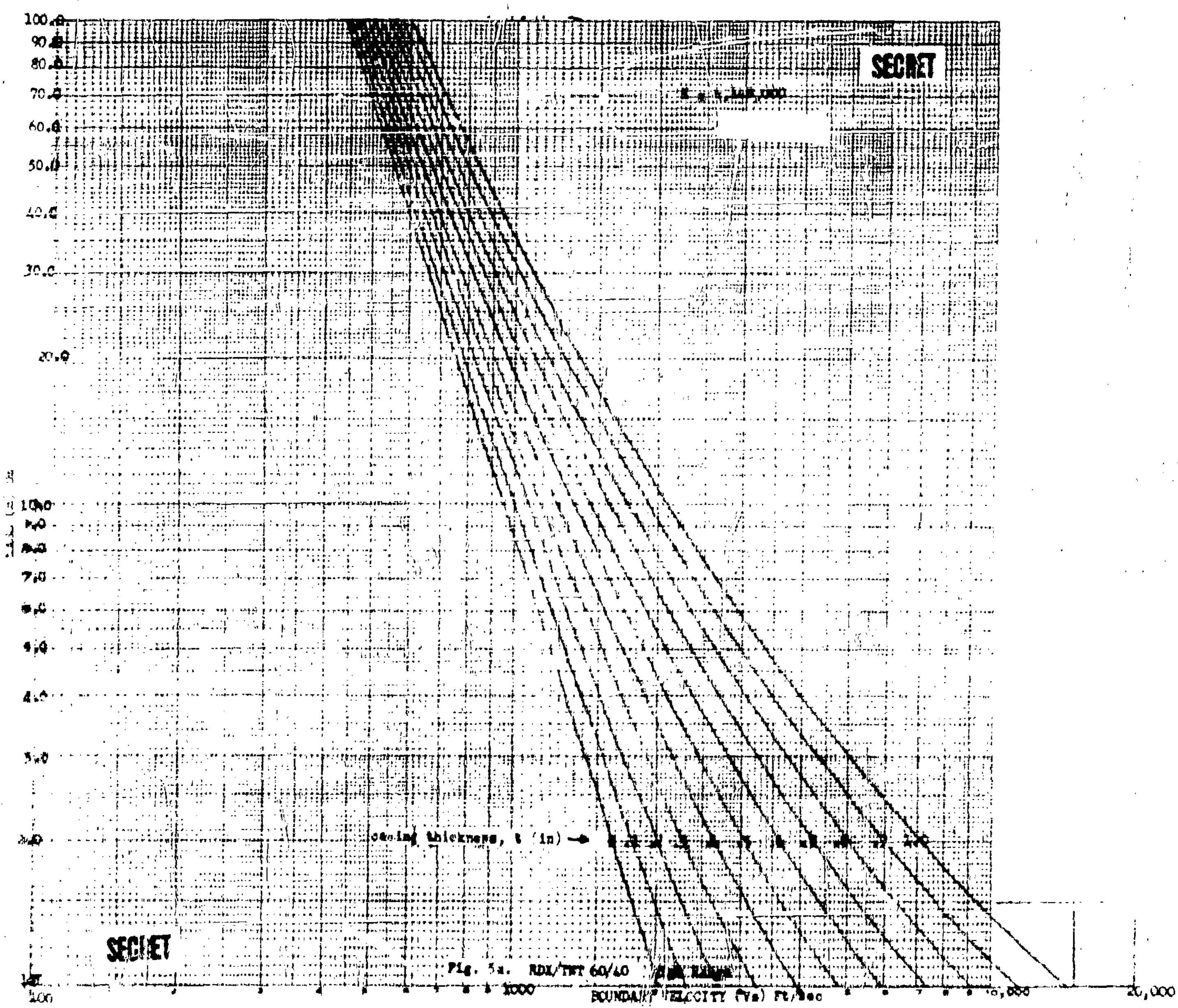

Fig. 5a. RDX/TNT 60/40

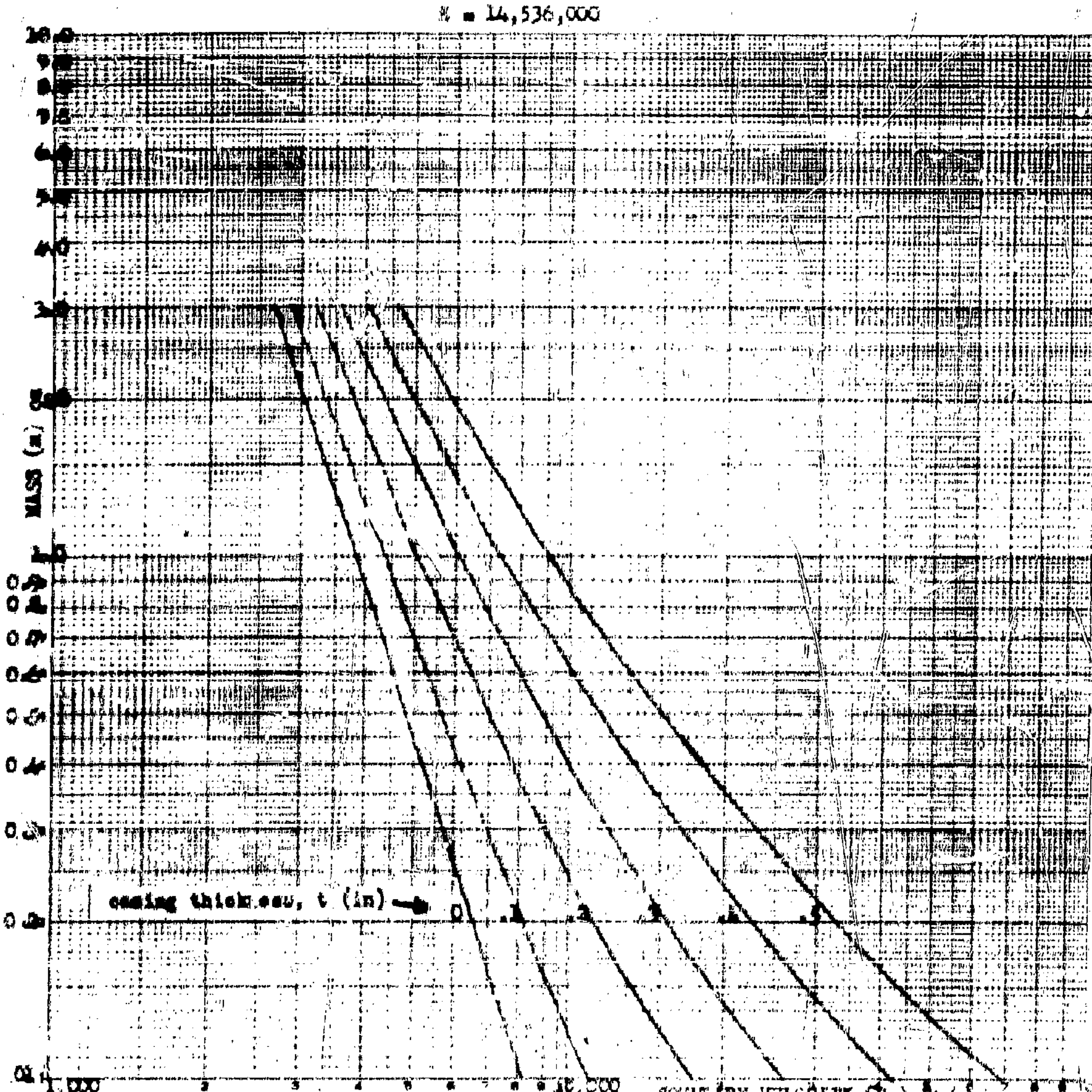

Fig. 6. Amatol Low Range

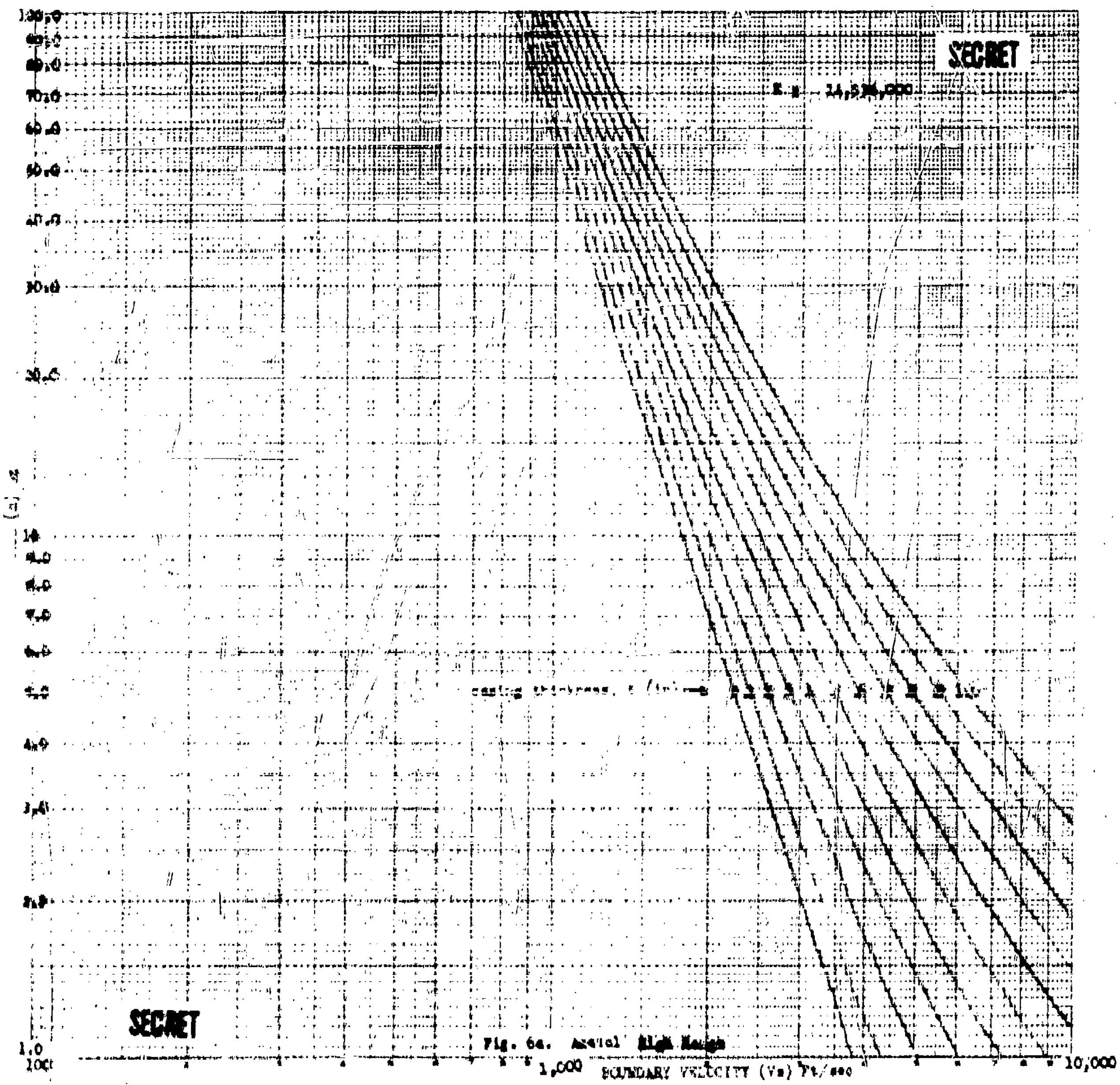

Fig. 6a. Axial High Range

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